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HAND WRITTEN NOTES
MECHANICAL ENGINEERING

BASIC THERMODYNAMICS

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Thermodynamics

It is the branch of science that deals with energy and energy interactions, and its effect on system and the surroundings.

Energy

It can be viewed as ability to cause changes -

System -

It is a fixed mass or region in space where our study is focussed (control vol)

Surroundings

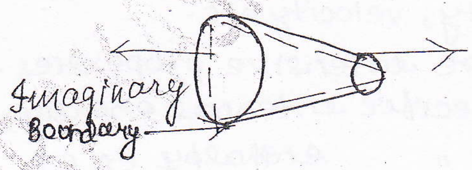
Every thing apart from the system forms the surrounding.

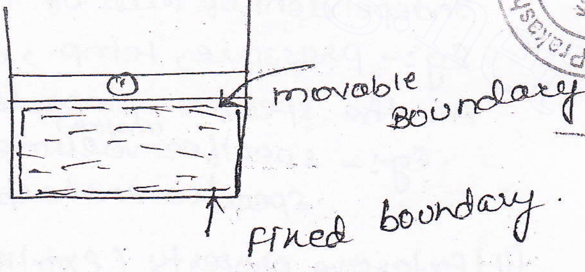
The part of the surrounding that is affected by the system is called immediate surrounding

Boundary

A real or imaginary surface that seperates system from the surroundings.

A boundary can be fixed or movable





Types of system

	Mass	Energy	Eg
closed	X	✓	Piston cylinder arrangement without valve.
open	✓	✓	piston cylinder arrangement with valves, nozzle, turbine etc.
Isolated	X	X	universe (a hot coffee contained in a perfectly insulated thermos)

Pressure

Gases

According to kinetic theory of gases the molecules of the gases are in random motion and during their random motion they colloid with one another and whatever comes their way These collision result in change of momentum and hence force, average normal force per unit area is termed pressure.

colloiding mass ∝ density

colloiding velocity $(C_{rms}) = \sqrt{\frac{3RT}{M}}$

$$\boxed{C_{rms} \propto \sqrt{T}}$$

Hence, pressure in gases is a function of $P = f(\rho, T)$.

liquid

In liquids the pressure is due to the repulsive forces between the molecules.

Properties

Any characteristic of a the system is called property of the system. The properties can be classified as

(i) Intensive (Intrinsic)

Independent of mass of the system under consideration

Eg:- pressure, temp., density, velocity etc.

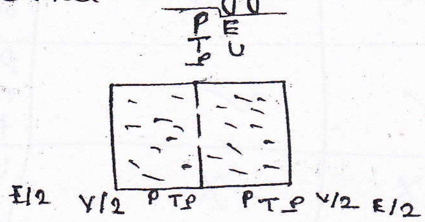
All the specific properties are intensive properties.

Eg:- specific volume (m^3/kg), specific internal energy, specific enthalpy, " enthalpy etc.

(ii) Extensive property (Extrinsic)

The properties which are dependent on the mass of the system under consideration is called extensive properties.

Eg:- Internal energy, enthalpy, Entropy etc.



Macroscopic & Microscopic approach

Macroscopic approach

In this approach individual molecular behavior is neglected and the average behavior is taken into consideration. This approach is valid till the continuum concept holds good.

Continuum

In this approach the matter is considered to be continuously distributed with no holes (voids) being present. The continuum concept is valid till the mean free path of the molecules is much much smaller than the system dimensions.

Microscopic approach

In this approach the individual molecular behaviour is considered. one of the method used is rarefied gas flow ~~do~~ theory

- The microscopic analysis is used in space exploration

State of the system and Process

- Any condition of the system is called state of the system
- The state of the system is specified by its properties, if any one of the property changes, state of the system changes.
- The change in state of the system is called process, the infinite state through which the system passes while moving from initial to a final state is called process path.
- The processes can be classified as:-

1) Quasi static (quasiequillibrium) & non-quasistatic

If a process occurs infinitely slowly it is called Quasistatic otherwise non-quasistatic.

~~A~~ A quasistatic process is represented by a joint line on the property diagram whereas a non-quasistatic process is generally represented by dashed line on property diagrams.

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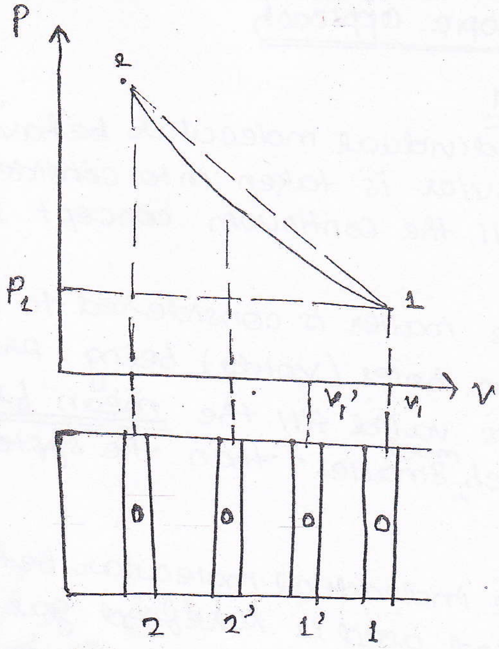
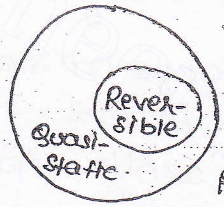


Reversible and Irreversible process

A process is said to be ~~irr~~reversible process if it can be reversed in the dirn. following the same path as that of the forward process, without leaving any effect on the system and the surroundings.

Note

All the reversible process are quasistatic but a quasistatic process may or may not be reversible.



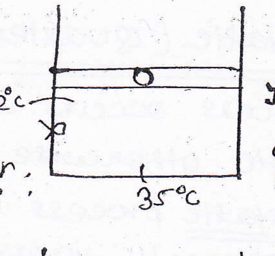
vapour is also gas but at condensation. steam is gaseous phase at high temp.

Thermodynamic equillibrium

A system is said to be in thermodynamic equillibrium if it satisfies the following equillibrium :-

(i) Thermal equillibrium

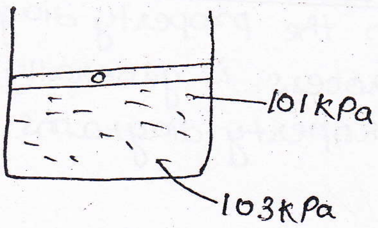
The temp. should be uniform in the system. System is said to be in thermal equillibrium with surroundings if the temp. of system & surr. is same.



Temp. is not uniform (not same at a particular instant)

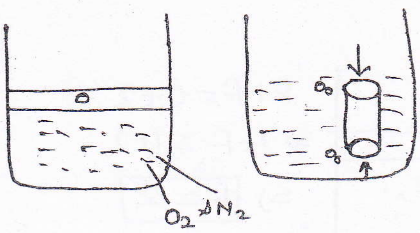
(ii) Mechanical equillibrium

The pressure at any pt. in the system should not change with time.



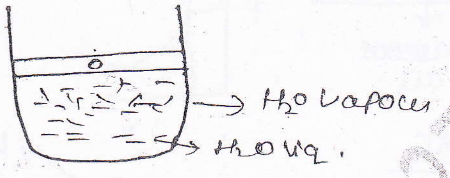
(3) chemical equilibrium

The chemical composition should not change with time.



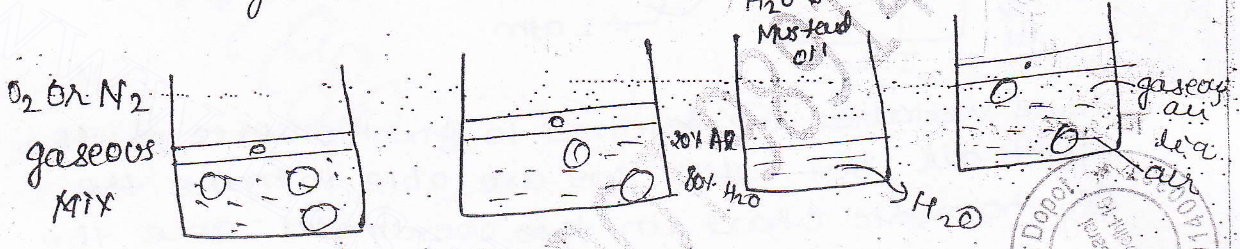
(4) Phase equilibrium

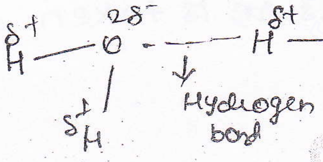
Amount of each phase should not change with time.


H_2O vapour
H_2O liq.

Pure substance

A substance is said to be a puresubstance if it is of homogenous chemical composition through out


O_2 or N_2 gaseous mix
H_2O & Mustard oil
20% AIR
80% H_2O
H_2O
gaseous air
liq. air


δ^+
$2\delta^-$
δ^+
δ^-
Hydrogen bond

(Responsible for high solubility)

Gibbs phase Rule

$$\boxed{P+F=C+2}$$

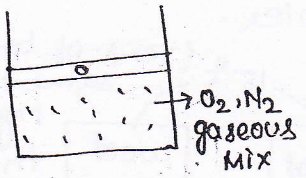
P → phases (liquid, solid, gas)
F → Degree of freedom
C → No. of chemical component

Equilibrium – No net change occur

Degree of freedom

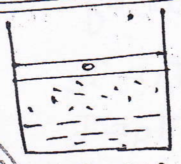
It is the minm no. of intensive independent variables required to fix the state of the system.

(1)


O_2, N_2 gaseous Mix

$P+F=C+2$
$\Rightarrow 1+F=2+2$
$\Rightarrow \boxed{F=3}$

(2) H_2O liquid & H_2O vap.



$P+F=C+2$
$\Rightarrow 2+F=1+2$
$\Rightarrow \boxed{F=1}$

(3) Triple point

$P+F=C+2$
$\Rightarrow 3+F=1+2$
$\Rightarrow \boxed{F=0}$

If 9kg ice is kept at triple pt. then no change occur as the system is in equilibrium.

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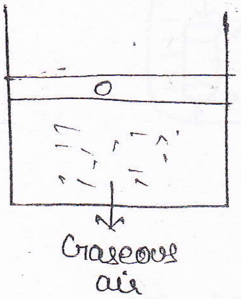
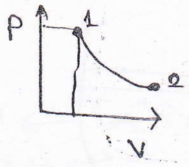


$P + F = C + 2$

$\Rightarrow 1 + F = 1 + 2$

$\Rightarrow \boxed{F = 2}$



If all components of air are taken such as H_2, N_2, O_2

$P + F = C + 2$

$\Rightarrow 1 + F = 4 + 2$

$\Rightarrow \boxed{F = 5}$ Not possible

$P_t = P_{O_2} + P_{N_2} + P_{CO_2} + P_v$

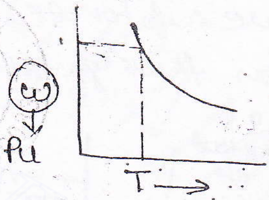
(5) RAC

MOIST AIR → water vap.
MOIST AIR → Dry air

$P + F = C + 2$

$\Rightarrow 1 + F = 2 + 2$

$\Rightarrow \boxed{F = 3}$



$\boxed{P_t} = P_a + P_v \rightarrow 1$ atm.

Three variables are required to fix the state of the Moist air but still we are able to make the Psychometric chart in two coordinates since the third variable i.e, the total pressure is taken as one atmosphere.

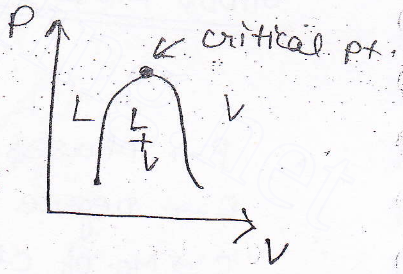
critical point

Neither liquid phase nor ~~p~~ vapour phase exist.

D.O.F = 0

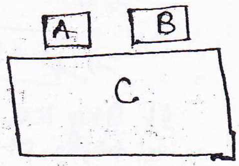
$T_{cr} = 373\,^{\circ}C$, $P_{cr} = 221$ bar

Gibbs phase rule fails at critical pt. Critical pt. is a fixed pt. and degree of freedom is zero.



Zeroth law of thermodynamics

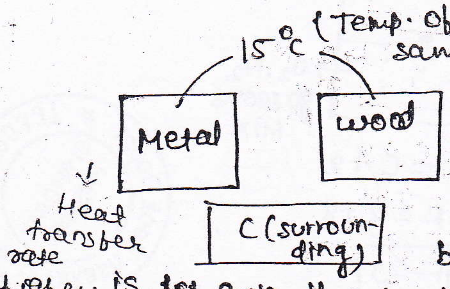
Stated in 1931 by scientist Fowler.



$T_A = T_C$

$T_B = T_C$

$\boxed{T_A = T_B}$



{Temp. of both remains same after keeping both the chairs in surr. for long time but metal is ~~fel~~ cooler due to feeling the we get through heat transfer.}

It states that if two bodies are in thermal equilibrium with a third then they are also in thermal equilibrium with each other.

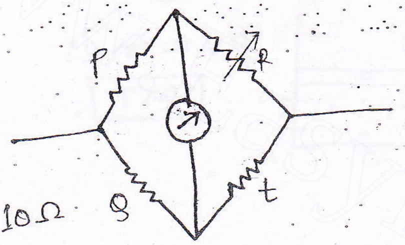
The concept of temp. measurement and thermometry is derived from zeroth law.

Thermometry

- Temp. measurement is based on finding the thermometric property.
- A thermometric property is one which helps in finding temp.

Types of thermometer

(1) Resistance thermometer / thermistor



$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{5}{10} = \frac{7}{S}$$

$$\Rightarrow \boxed{S = 14}$$

for eg. if $S = S_0(1 + \alpha t + \beta t^2)$

S_0, α & β are const.

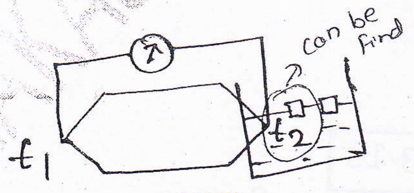
Range (500 to 1000°C)

Resistance plays the role of thermometric property.

It is based on the wheat stone bridge principle.

(2) Thermocouple

Seeback effect



It is based on seeback effect. A/c this effect if two different metals are joined to form two different junctions and these junctions are kept at different temperature then an emf is generated which is directly proportional to temp. difference. By measuring temp. difference unknown temp. can be found.

$$\boxed{Emf \propto \Delta t}$$

Emf is thermometric property

- Emf (voltage, current) plays the role of thermometric property.

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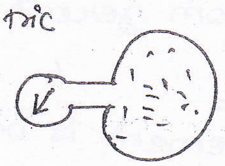
The opposite of the seeback effect is called the Peltier effect and is used in thermoelectric refrigeration (1000 to 1500)

(3) constant volume thermometer

- Pressure plays the role of thermometric property.
- In both const. vol. & const. press. the material of construction is an ideal gas.
- Ideal gas thermometer is indepent of material of construction.

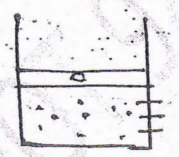


$PV = mRT$

$P \propto T$

(4) Constant pressure thermometer

- Volume plays the role of thermometric property.

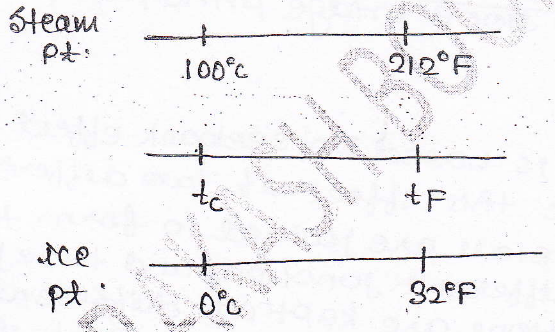


$PV = mRT$

$\boxed{V \propto T}$

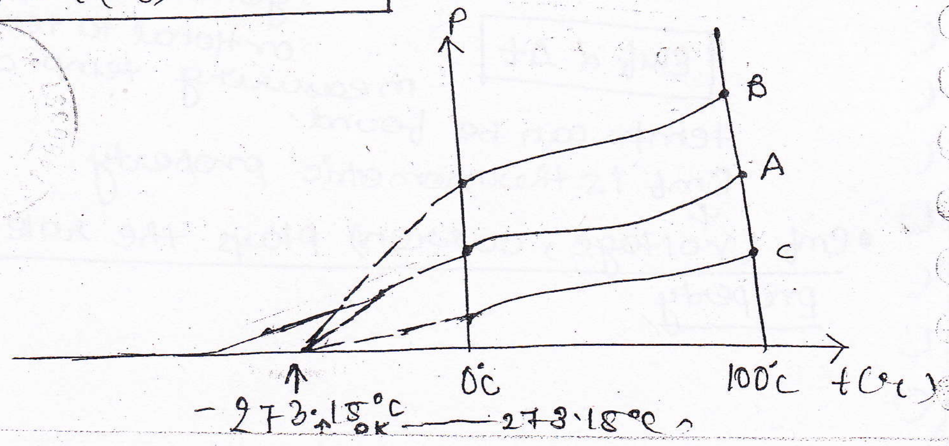
11|11|13

Temperature Scale



$$\boxed{\frac{t_C - 0}{100-0} = \frac{t_F - 32}{212-32}}$$

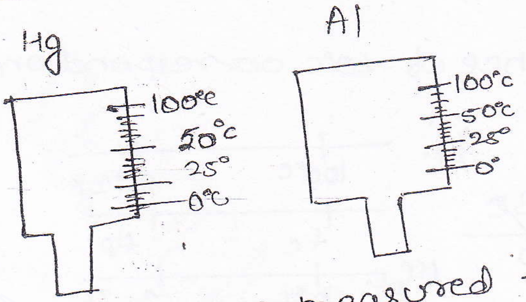
$$\boxed{T(k) = t(°c) + 273.15}$$



Kelvin scale is an absolute and thermodynamic temp. scale.

Another absolute and thermodynamic temp. scale is called Rankine scale and is linked with the Farenheit scale.

Caliberation of thermometer



Hg
$0-100°c \rightarrow 100cm$
$1cm = 1°c$

Al
$0-100°c \rightarrow 200cm$.
$2cm = 1°c$.

Min. temp. measured $\rightarrow 10^{-9} K$

- If two different thermometers having different materials as thermometric fluid then if they are placed at the same place it can not be guarantee that they will give the same reading anywhere except the caliberation pts.
- But ~~be~~ they are guarantee to ~~so~~ read same at the caliberation pts.

Method used before 1954

Before 1954 the temp. measurement was based on two reference pts. namely ice pt. and steam pt.

Note :-
when nothing is mentioned in thermometry we always have to assume in linear variation.

$$t = ap + b \quad \text{—} ①$$

ice point

$$t_i = ap_i + b \quad \text{—} ②$$

steam point

$$t_s = aP_s + b \quad \text{—} ③$$

$$\frac{① - ②}{③ - ②}$$

$$\boxed{\frac{t - t_i}{t_s - t_i} = \frac{\cancel{a}(P - P_i)}{\cancel{a}(P_s - P_i)}}$$

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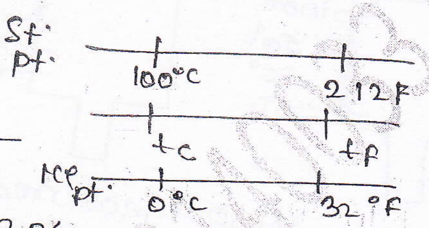
Method used after 1954

After 1954 a single reference pt. that is triple point of water is used for temp. measurement. According to internationally accepted convention 1 kelvin is defined as $\left(\frac{1}{273.16}\right)^{th}$ of triple pt. of water.

(Q) what does a temp. difference of 10°c correspond on a farenheit scale.

Soln →



$$\frac{1\cancel{0}}{10\cancel{0}} \neq \frac{t_F - 3\cancel{2}}{18\cancel{0}}$$

$$\Rightarrow \frac{1\cancel{80}}{\cancel{10}} = 1\cancel{0}t_F + 3\cancel{2}0 \Rightarrow \cancel{t_F} \neq 18$$

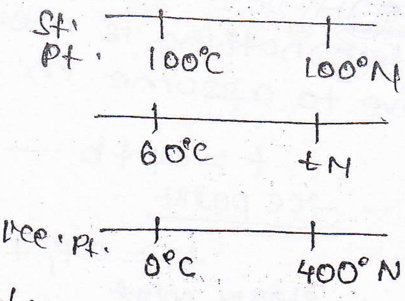
$$\frac{t_c - 0}{100 - 0} = \frac{t_F - 32}{212 - 32} \Rightarrow 1.8\,t_c = t_F - 32$$

$$\Rightarrow 1.8\,dt_c = dt_F - 0$$

$$\Rightarrow dt_F = 1.8 \times 10 = 18.$$

(Q) A new temp. scale ~~deo~~ '°N' is to be define, the boiling and the freezing pts. on this scale are 100°N and 400°N resp. what will be the reading on new scale corresponding to 60°c.

Sol →



$$\frac{60 - 0}{100 - 0} = \frac{t_N - 400}{100 - 400}$$

$$\Rightarrow \frac{6}{10} = \frac{t_N - 400}{-300}$$

$$\Rightarrow 1800 = 4000 - 10t_N$$

$$\Rightarrow \boxed{t_N = 220°N}$$

(Q) At what temp. '°c' and farenheit scale will give the same reading.

Soln –

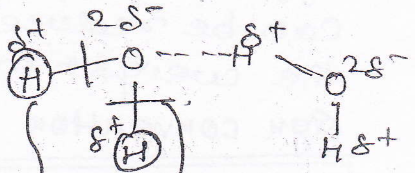
$$\frac{t_c - 0}{100 - 0} = \frac{t_c - 32}{180} \Rightarrow \frac{t_c}{100} = \frac{t_c - 32}{180}$$

$$\Rightarrow 180t_c - 100t_c = -3200 \Rightarrow 80t_c = -3200$$

$$\Rightarrow t_c = -40°F$$

Energy and Energy interactions

$$\text{Energy} = \underbrace{\text{Macroscopic}}_{K.E + P.E} + \text{Microscopic}$$



δ^+
H
$2\delta^-$
O
H
δ^+
δ^+
H
$O^{2\delta^-}$
$H\delta^+$

Microscopic (Internal energy)
= sensible energy + latent energy + chemical energy + Nuclear energy.
(random molecular motion)

chemical energy is transformed into sensible energy.

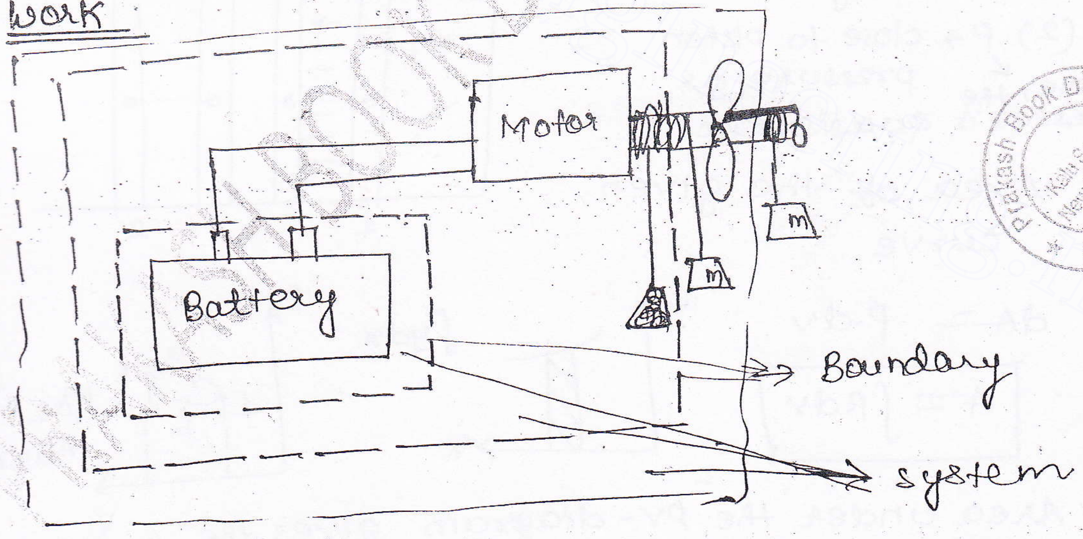
K.E + vibration + spin + rotation.

A system can interact with the surroundings in the form of energy in following three ways:-

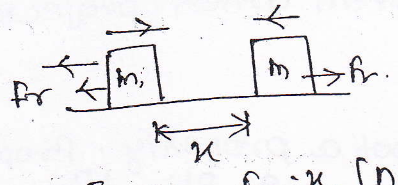
(1) Mass
(2) work
(3) heat

Electrical energy can not be used directly it need some transformation.

Work



Motor
Battery
m
m
Boundary
system



work is zero when the dirn of force are opposite (it does not depend on displacement).

Net $W = -F_r \cdot x - f_r \cdot x$ (non-zero),

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- Work is said to be done by the system if the sole effect on the things external to the system can be reduced to raising of weights, though the weight may not be actually raised.

Sign convention

According to the sign convention work done by the system is taken as +ve and work done on the system is taken as –ve.

Closed system analysis

$F = P \times A$

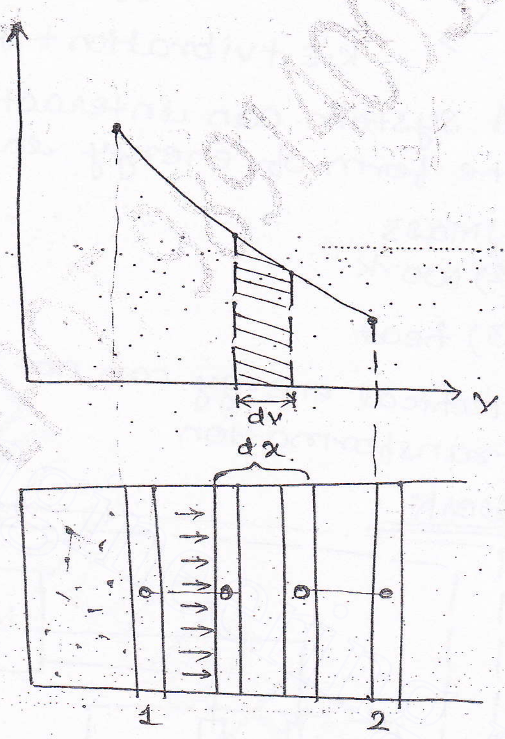
$\delta W = \vec{F} \cdot \vec{dx}$

$= F \cdot dx$

$= P \cdot \underbrace{A \cdot dx}_{\text{Swept vol}}$

$\delta W = P \cdot dV$

$W = \int P \cdot dV$



(1) Closed system.

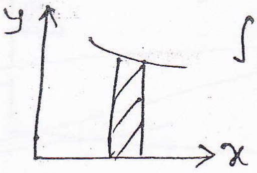
(2) P → close to piston pressure or

Here, the pressure is Quasistatic.

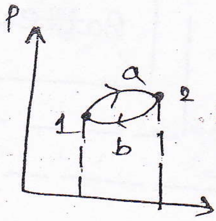
Area of the given curve

$dA = P \cdot dV$

$$\boxed{A = \int P \cdot dx}$$



$\int y\,dx$.



$W_{1a2} \neq W_{1b2}$

$A_{1a2} \neq A_{1b2}$

- Area under the PV-diagram gives the work interaction as for a closed system when projected on volume axis.

Important pts. w.r.t work

- It is a Path function. It is not a property. Property is a pt. fn.
- It is a Boundary phenomena.

- It is a transient phenomena. work can't be defined at an instant.
- It depends on past history (force, displacement etc).
- Work in various non-flow processes

Non-flow process (Pdv, boundary, closed system)

(1) Isochoric

(Const. vol., isometric)

[Rigid const.]

$\boxed{W = 0}$

(2) Isobaric

(const. press., isopiestic)

$$W = \int P dv$$

$$= P \int_1^2 dv$$

$$\boxed{W = P(V_2 - V_1)}$$

(3) Isothermal (const.)

(1) Closed system.

(2) Quasistatic system.

(3) Ideal gas.

$$W = \int P dV$$

In Ideal gas

$$PV = mRT$$

$$PV = const$$

$$PV = C$$

$$W = \int_1^2 \frac{C}{V} \cdot dV$$

$$= C \ln \frac{V_2}{V_1} = C \ln \frac{P_1}{P_2}$$

$$\boxed{C = P_1V_1 = P_2V_2 = mRT}$$

[4] Adiabatic

Conditions required

(1) closed.

(2) Quasistatic

$PV^{\gamma} = const.$

(1) Adiabatic

(2) Ideal gas.

(3) Reversible for both open as well as closed

Also these three conditions required.

$$W = \int P dv$$

$$PV^{\gamma} = C$$

$$P = \frac{C}{V^{\gamma}}$$

$$W = \int_1^2 \frac{C}{V^{\gamma}} dV$$

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$$\Rightarrow W = C\left\{\frac{V_2^{-\gamma+1} - V_1^{-\gamma+1}}{-\gamma+1}\right\}$$

$$W = C\left\{\frac{\overset{P_1V_1^{\gamma}}{V_1^{-\gamma+1}} - \overset{P_2V_2^{\gamma}}{V_2^{-\gamma+1}}}{\gamma-1}\right\}$$

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{\gamma-1}}$$

Polytropic process

$$PV^n = \text{const}$$

$$-\infty < n < \infty$$

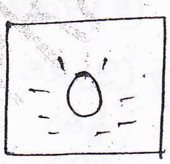
For generally occuring process → $\boxed{1 < n < \gamma}$

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{n-1}}$$

Condition for PV^γ

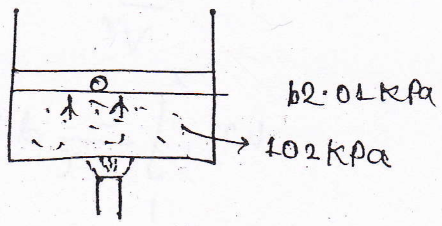
Visualization or realisation of process

(1) Constant volume

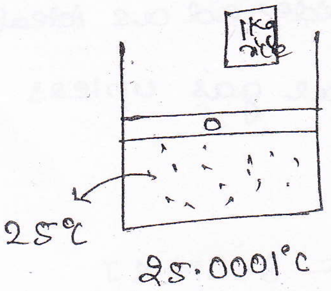


(2) constant pressure

If the external forces (except the gas pressure) are not changing and the piston is free to move.

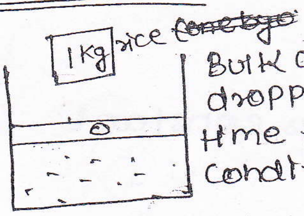


(3) Isothermal process



If Isothermal process has to be carried out for the single phase of the substance than it must be carried out in a very slow manner. Isothermal process can be a fast process also if it is carried out for the phase change of the substance.

(4) Adiabatic



Bulk amount is dropped at a time thus the condition to be fulfilled is either

$Q \to 0$ [when insulated)

$dt \to 0$ [very high heat transfer.

If an adiabatic process has to be carried out without insulation then it must be carried out in a very fast manner.

(5) Polytropic

If generally the polytropic term is used when the polytropic index 'n' lies b/w ~~const~~ 1 & γ.

In this type of process the heat transfer occurs but it is not sufficient enough to ensure temp. of the substance as constant.

Ideal gas

Assumptions for Ideal gas behavior

- Intermolecular forces are negligible.
- volume occupied by the molecules themselves are negligable compared to the container volume.

Favourable condition for Ideal gas behaviour

1) low pressure
2) High temp. (Compared to the critical temp. and pressure)

Imp. points

- All the substances which are gases at normal conditions will always be treated as ideal gases unless mentioned.

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Eg :- O_2, N_2, air, helium, argon, SO_2, CO_2 etc.

- water vapour should always be considered as ideal gas unless mentioned.
- steam should never be taken as ideal gas unless mentioned

$$PV = n\bar{R}T$$

$\bar{R}$ = universal gas const = $\dfrac{8.314\ kJ}{k\text{-mol}\,k}$

n = kilomoles.

$$PV = mRT$$

R = Characteristic gas constant.

$$R = \frac{\bar{R}}{M} \rightarrow \text{Molecular mass}$$

$$R_{O_2} = \frac{\bar{R}}{M} = \frac{\dfrac{8.314\ kJ}{k\text{-mol}\,k}}{32\ kg/k\text{-mol}} = \frac{8.314}{32}\ \frac{kJ}{kg\text{-}k}$$

1 mol O_2 → 32g.
1 k mol O_2 → 32 kg.
1 k-mol or 1 kgmol.

Ideal gas eqns for various processes

$$PV = mRT$$

$$\frac{PV}{T} = \text{const}$$

Constant volume

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

Constant pressure

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$

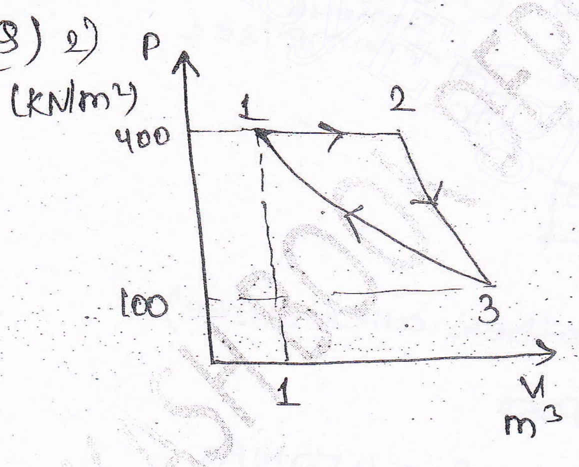
Note :-

- For a process going from left to right on the P-V diagram work is done by the working fluid.
- For a cycle the net work done is equal to area enclosed by the cycle on P-V diagram.
- All clockwise cycles on P-V diagram are Power producing cycles and all anticlockwise cycle are Power consuming cycle.

P.K Nag (Q) 2.5 , 3.12 — $PV^{1.2}$ const.

(Q) 1) A spherical balloon of 1 m dia. contains a gas at 150 kPa. The gas inside the balloon is heated until pressure reaches 450 kPa. During the process of heating the pressure of the gas inside the balloon is proportional to the cube of dia. of the balloon. Find the net work done by the gas.

(Q) 2)



1-2 → Isobaric
2→3 → Polytropic (n = 1.4)
3→1 → Isothermal process (PV = const.)

Find (i) V_2
(ii) Net work transfer.

(3.12) 101.325 kPa → atm. pressure.

$V_2 = \frac{V_1}{5}$

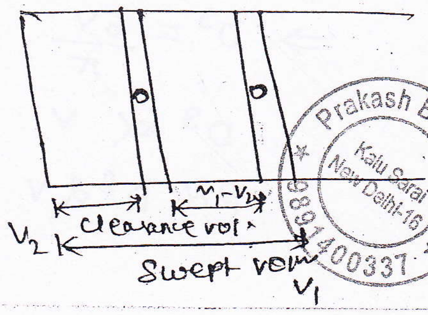
$PV^{1.2} = \text{const}$.

D = 0.15 m
L = 0.25 m

$P_1 V_1^{1.2} = P_2 V_2^{1.2}$

$\Rightarrow P_1 V_1^{1.2} m^{1.2} = P_2 V_2^{1.2} m^{1.2}$

−ve sign signify that work is done on the system.



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$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

Compressors are open system.
Here, the system is taken as close system because only compression is included here.

$$P_1V_1^{1.2} = P_2V_2^{1.2}$$

$$\Rightarrow P_2 = P_1 \times \left(\frac{V_1}{V_2}\right)^{1.2}$$

$$\Rightarrow P_2 = 699\, kPa.$$

$$V_1 - V_2 = \frac{\pi}{4} D^2 \times L$$

$$5V_2 - V_2 = \frac{\pi}{4}(0.15)^2 \times 0.25$$

$$\Rightarrow V_2 = 1.1044 \times 10^{-3}\, m^3.$$

$$\Rightarrow V_1 = 5.5223 \times 10^{-3}\, m^3.$$

$W = -1.046$ kj/mol/comp./cylinder.

$W_T = 2W$ kj/comp. (There are two cylinders thus $\xrightarrow{2\times1.046}$ comp./sec

$$P = \underset{kj/comp.}{-2\times1.046} \times \frac{500}{60}$$

$$\boxed{P = -17.446\ KW}$$

(9) $P \propto D^3$

$P = KD^3$ (Another alternative)

$P_1 = 150\, kPa$, ~~RAT~~

$D_1 = 1m$, $V_1 = \frac{\pi}{6}$, $P_2 = 450\, kPa$.

$$V = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3$$

$$V = \cancel{4}\frac{\pi}{6}D^3$$

$$\Rightarrow D^3 = \frac{6V}{\pi}$$

$$D^3 \propto V$$

$$P \propto D^3 \propto V$$

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Isothermal

$$\boxed{P_1V_1 = P_2V_2}$$

Adiabatic

$$PV^{\gamma} = \text{const.}$$

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$\frac{PV}{T} = \text{const.}$$

$$V \propto \frac{T}{P}$$

$$P\left(\frac{T}{P}\right)^{\gamma} = \text{const.}$$

$$\frac{T^{\gamma}}{P^{\gamma-1}} = \text{const.}$$

(2) $$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}}$$

(3) $$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

Conditions required

1) Adiabatic
2) Reversible
3) Ideal.

Polytropic

$$PV^{n} = \text{const.}$$

$$\left.\begin{aligned} \frac{T_2}{T_1} &= \left(\frac{P_2}{P_1}\right)^{n-1/n} \\ T_1V_1^{n-1} &= T_2V_2^{n-1} \end{aligned}\right\}$$

Condition required

Ideal gas.

$$\left[\begin{aligned} &PV^{1.2} = \text{const.} \\ &\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{1.2-1/1.2} \end{aligned}\right.$$

only one condition

Ideal gas.

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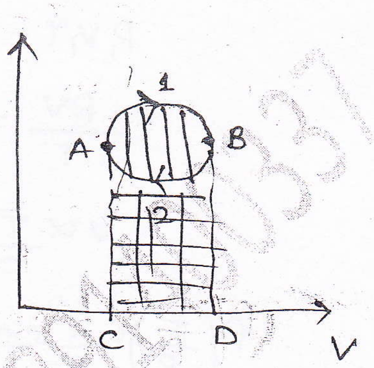
(9) An imaginary engine receives heat and performs work on a slowly moving piston at such a rate that the cycle of operation of one kg of fluid can be represented as a circle of 10cm dia. on PV-diagram. The scale is 1 cm = 300 kPa on Y-axis and 1cm = 0·1 m³ on x-axis. Find the net work done.



Left to right → in dirn of increasing vol. (vol. of fluid ↑).

Sol :-

$$W = \int P\,dv$$

$$= \text{area of } A1BDC$$

$$- \;\;"\;\;\;\;"\;\; A2BDC.$$

As area is decreasing thus work done on the system (A2B).

work done by A1B > A2B.

means w.D " the system > on " " ,

∴ Net work done +ve.

$$W = \frac{\pi}{4}(10)^2\ \underbrace{cm}_{\downarrow\ 300kPa} \times \underbrace{cm}_{\downarrow\ 0.1m^3}$$

$$= \frac{\pi}{4}(10)^2 \times 300 \times 0.1 \ \underbrace{\left(\frac{kN}{m^2} \times m^3\right)}_{\rightarrow kJ.}$$

$$\boxed{W = 2356.19\ kJ}$$

Scale large → Graph small.

[If we take 1cm = 600 kPa.
1cm = 0·2 m³].

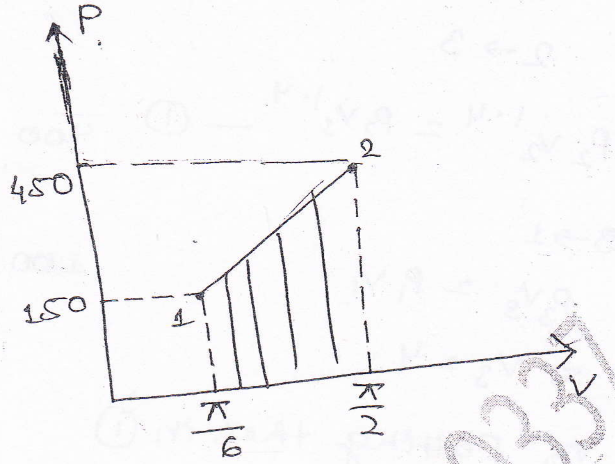
$P \propto V$

$\boxed{P = KV}$ → linear

$$\frac{P_1}{P_2} = \frac{V_1}{V_2}$$

$$\frac{150}{450} = \frac{\pi/6}{V_2}$$

$\Rightarrow V_2 = \frac{\pi}{2}$



work done

= Area of trapezium

$$= \frac{1}{2}(450+150) \times \left(\frac{\pi}{2} - \frac{\pi}{6}\right)$$

$= 314.159$ kJ

Alternative

Let the process be polytropic.

$PV^n = \text{const}$

$P_1V_1^n = P_2V_2^n$

$n = -1$, $\quad w = \frac{P_1V_1 - P_2V_2}{n-1}$

Another Alternative

$P \propto D^3$

$P = KD^3$

$w = \int P\,dV$

$V = \frac{\pi}{6}D^3$

$dV = \frac{\pi}{6} \times 3D^2 d(D)$

when the process is not linear then integrate the relation.

$P \propto D$

$V = \frac{\pi}{6}D^3$

$D \propto V^{1/3}$

$P \propto V^{1/3}$

$P = KV^{1/3}$

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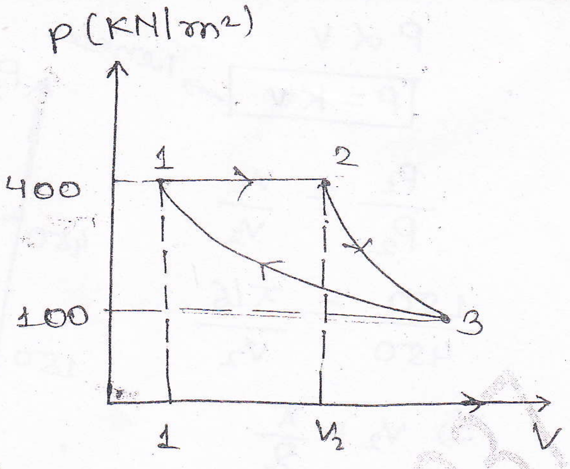
(8) 1 → 2

2 → 3

$P_2 V_2^{1.4} = P_3 V_3^{1.4}$ — ①



3 → 1

$P_3 V_3 = P_1 V_1$

$\Rightarrow V_3 = 4.$

~~V_2~~ Putting thes in ①

$V_2 = 1.486 m^3.$

Net work done

$= w_{12} + w_{23} + w_{31}$

$= 400(V_2 - V_1) + \frac{P_2V_2 - P_3V_3}{n-1} + P_1V_1 \ln\frac{V_1}{V_3}$

$= 125 J$

$W_{31} = C \ln\frac{V_1}{V_3}$

$C = mRT = PV$

$\therefore W_{31} = P_1V_1 \ln\frac{V_1}{V_3}$

Slope of constant temp. and adiabatic curve on PV-diagram for an ideal gas

Isothermal

Adiabatic curve is more steeper than Isothermal curve.

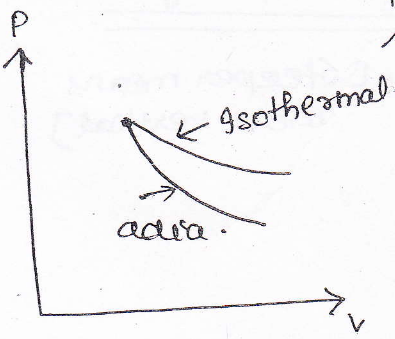
$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ → Ellips.

when $a = b$

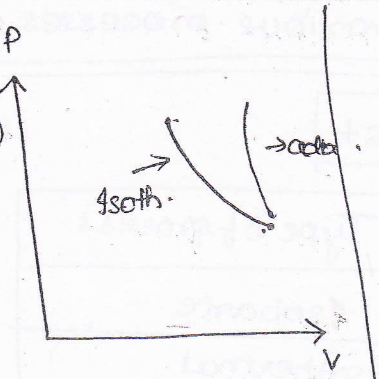
$x^2 + y^2 = a^2$ → circle.

$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$

when $a = b$



expansion



compression

$x^2 - y^2 = a^2$
↳ Rectangular hyperbola.

Also, $xy = \text{cost}$.

$x = ax^2$
$y = by^2$ } Parabola.

$y = ax + b$] straight line.

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Isothermal

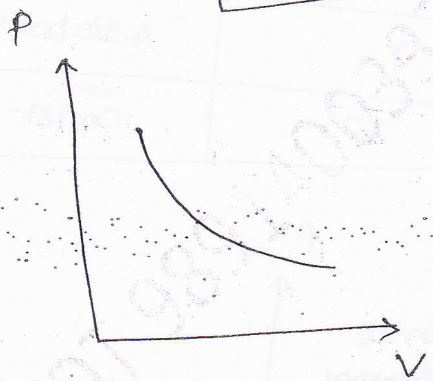
$PV = mRT$

$PV = \text{const.}$

$PdV + VdP = 0$.

$\Rightarrow PdV = -VdP$

$$\Rightarrow \boxed{\frac{dP}{dV} = -\frac{P}{V}}$$



Isothermal curves are hyperbolic.

Necessary condition for adiabatic are
i) Reversible
ii) Ideal.

Adiabatic

$PV^{\gamma} = C$

$\Rightarrow P \cdot \gamma \cdot V^{\gamma-1} dV + V^{\gamma} \cdot dP = 0$.

$\gamma \cdot P \cdot dV + V \cdot dP = 0$.

$$\boxed{\frac{dP}{dV} = -\gamma \frac{P}{V}}$$

Slop is γ times Isothermal.

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- Adiabatic curve is more steeper than Isothermal curve on PV-diagram.
- The slope of adiabatic curve is γ-times the Isothermal curve on PV-diagram.

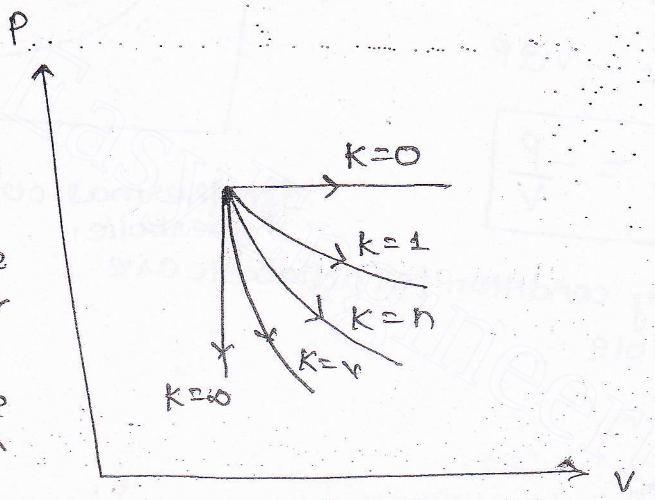
Representation of various processes on P-V diagram

$\boxed{PV^k = \text{const}}$

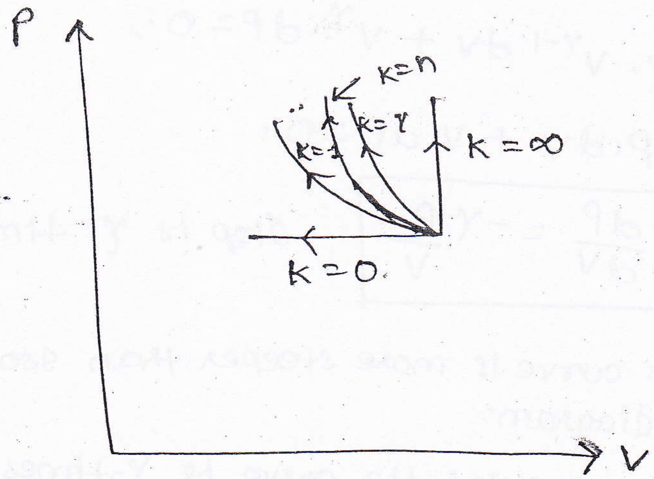
- [Steeper means more vertical]

Value of K	Type of process
0	Isobaric
1	Isothermal
n	Polytropic
γ	Adiabatic
∞	Const. vol.

- Polytropic curve is b/w isothermal & adiabatic
- Isothermal curve is ~~to~~ rectangular hyperbola.
- Adiabatic curve is more steeper means more vertical than isothermal.



Expansion



Compression

Heat

$Q \propto m$

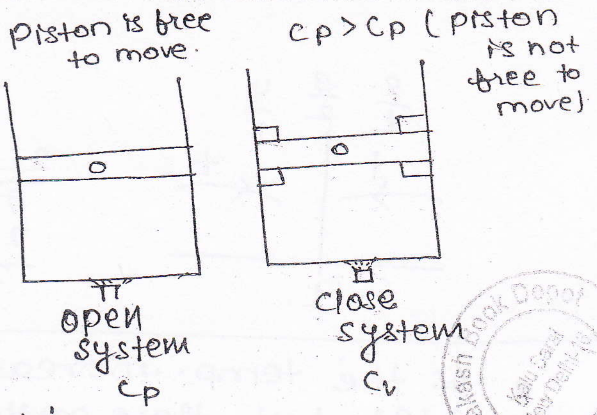
$Q \propto \Delta T$

$$Q = mc\Delta T$$

$\downarrow$ specific heat

$mc \rightarrow$ Heat capacity.

$$c = \frac{Q}{m \times \Delta T} \quad \frac{kJ}{kg\text{-}K} \text{ or } \frac{kJ}{kg\text{-}°C}$$

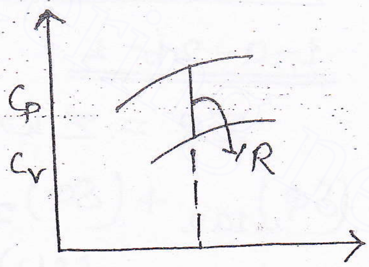


- Heat is the form of energy which is transferred by the virtue of temp. difference.
  Heat energy stored is thermal energy.
- Specific heat is defined as amount of energy required to change the temp. of unit mass of substance through unit degree temp. difference.
- Specific heat at const. pressure is always greater than specific heat at const. volume since Cp includes both internal energy as well as boundary work whereas Cv includes only internal energy.

$$\boxed{\gamma = \frac{C_p}{C_v}}$$

$T\uparrow, C_p\uparrow, C_v\uparrow$

$$\gamma = \left(\frac{C_p\uparrow}{C_v\uparrow}\right)\downarrow$$

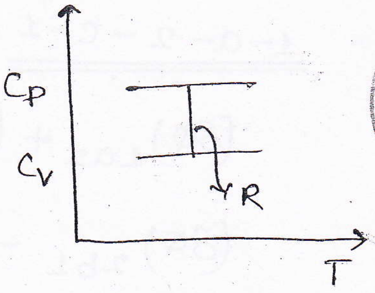


$$\boxed{C_p - C_v = R}$$

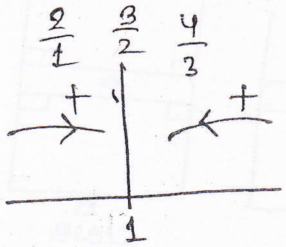
$\boxed{\text{For monoatomic}, \ \gamma = 1.67}$

$\boxed{\text{diatomic}, \ \gamma = 1.4}$

$\boxed{\text{Triatomic or Polyatomic}, \ \gamma = 1.33}$



Monoatomic



$$\frac{22}{7} = 3.14$$

$$\frac{27.10}{7+10} = \frac{32}{17} = 1.88$$

- As the temp. increases both C_p and C_v increases but there ratio γ decreases for diatomic and polyatomic gases.
- For monoatomic gases C_p, C_v and hence γ does not change with change in temp.

First law of thermodynamics

Statement

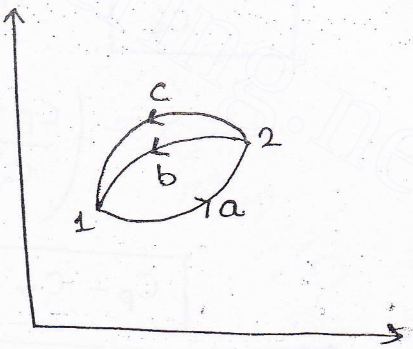
For a closed system undergoing a cycle net heat transfer is equal to net work transfer. It is valid for reversible as well as irreversible cycle.

$\boxed{\Sigma Q = \Sigma W}$ → for both reversible & irreversible.

Consequences of 1st law of thermodynamics

(1) Heat transfer is a path function.

1-a-2-b-1



$$\Sigma Q = \Sigma W$$

$$(\delta Q)_{1a2} + (\delta Q)_{2b1} = (\delta W)_{1a2} + (\delta W)_{2b1}$$

1-a-2-c-1

$$(\delta Q)_{1a2} + (\delta Q)_{2c1} = (\delta W)_{1a2} + (\delta W)_{2c1}$$

$$(\delta Q)_{2b1} - (\delta Q)_{2c1} = \underbrace{(\delta W)_{2b1} - (\delta W)_{2c1}}_{x} \quad \text{— Ⓐ}$$

$$(\delta Q)_{2b1} = (\delta Q)_{2c1} + x$$

whether $(\delta Q)_{2b1} = (\delta Q)_{2c1}$ depends on x and x is the path, it means its equality or inequality depends on path function.

Imp. pts. w.r.t to heat transfer

Sign convention

- Heat added to the system is +ve whereas heat rejected by the system is taken as −ve.
- It is a path f^n. It is not a property.
- It is a boundary phenomena.
- It is a transient phenomena.
- It depends on past history.

(2) Energy is a property

From eqn – Ⓐ

$$(\delta Q)_{2b1} - (\delta W)_{2b1} = (\delta Q)_{2c1} - (\delta W)_{2c1}$$

$$(\delta Q - \delta W)_{2b1} = (\delta Q - \delta W)_{2c1}.$$

$$\delta Q - \delta W = dE$$

$$\boxed{\delta Q = \delta W + dE}$$

↳ 1st law of thermodynamics for closed system.

Tough path b and c are different but the end points are same and the quantity $(\Delta Q - \Delta W)$ is same for both the paths and hence it must represent a change in property and that property is called energy.

- Random collision of molecules cause only heat transfer.
- " " " Bulk molecules " " work " .

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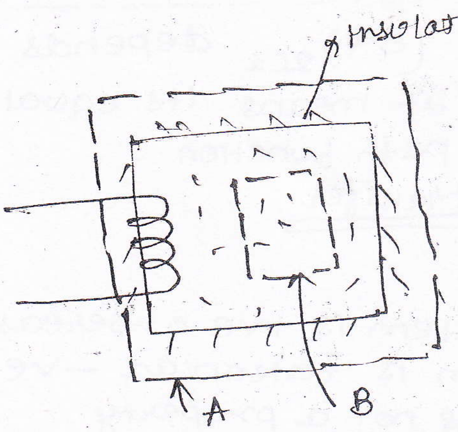
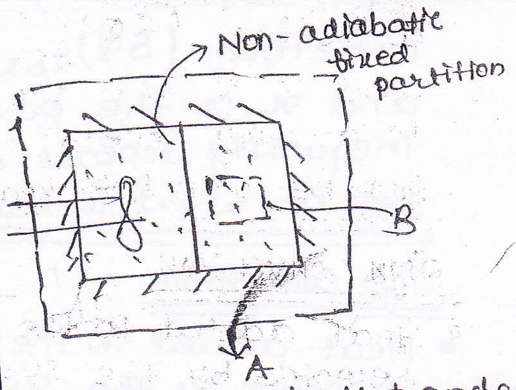


No energy transfer through A as Black boundary is insulated.

Through B only heat energy transfer takes place (As random collision of molecules takes place).



Here, A both transfer of heat and work takes place as the rotor is rotating and converted into work. Here, energy is in the form of work.

① Closed system

$$\boxed{\delta Q = \delta E + \delta W}$$

② $\Delta K.E = 0$ & $\Delta P.E = 0$ (stationary system)

$$\delta Q = du + \delta w$$

$$\delta Q = du + \delta w_b + \delta w_o$$

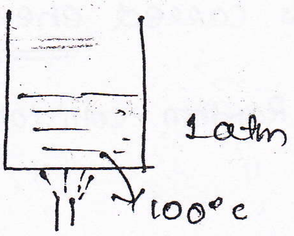
- $\delta w_b \rightarrow$ Boundary work (Pdv)
- $\delta w_o \rightarrow$ other work (Electrical or Shaft work)

(3) $\delta w_o = 0$ & quasistatic process

$$\delta Q = du + Pdv$$

- specific heat of boiling water is infinity

$$C = \frac{Q}{m \times (\underbrace{dT}_{\text{no change } = 0})} = \infty$$



Note

specific heat of phase change of substance is not defined and hence we define a new term for phase change called latent heat.

Ⓠ ① A piston cylinder device contains $0.05\ m^3$ of a gas initially at 200kPa and ~~th~~ at this state a linear spring which has a spring constant of 150 kN/m is just touching the piston but exerting no force on it. Now heat is transferred to the gas causing the piston to rise and to compress the spring until the vol. inside the cylinder doubles. If the cross section area of the piston is $0.25\ m^2$. find

(1) the final pressure inside the cylinder

(2) work done by the gas.

Ⓠ ② An ideal gas is heated at constant volume until its temp. is three times the original temp. It is then expanded isothermally till it reaches its original pressure. The gas is then cooled at constant pressure till it is restored to the original state. Represent this cycle on pv-diagram and find the net work for one kg gas. Represent your answer in terms of gas constant R. Take initial temp. as 350K.

Ⓠ J. 20

- For stationary system, potential and kinetic energy are zero.

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13|11|13

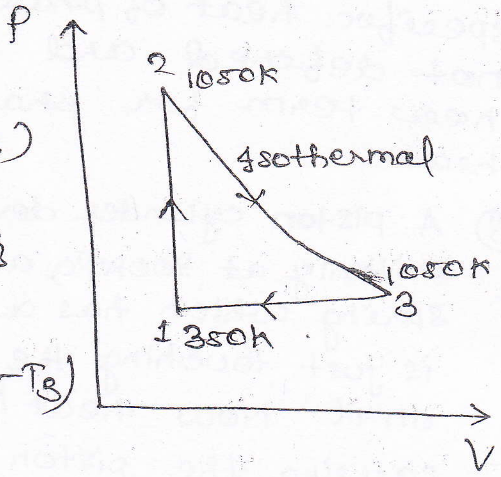
(92) sol) Wnet

$= W_{12} + W_{23} + W_{31}$

$= 0 + c \ln \frac{V_3}{V_2} + P(V_1 - V_3)$

$= mRT \ln\left(\frac{V_3}{V_2}\right) + P_1V_1 - P_3V_3$

$= mRT \ln\left(\frac{V_3}{V_2}\right) + mR(T_1 - T_3)$


P
2 1050K
Isothermal
1050K
3
1 350K
V

$P_2V_2 = P_3V_3$

$\frac{V_3}{V_2} = \frac{P_2}{P_3} \quad [P_3 = P_1]$.

$\therefore \frac{V_3}{V_2} = \frac{P_2}{P_1}$

$3 \rightarrow 1$

$\frac{V_3}{T_3} = \frac{V_1}{T_1} \quad [V_1 = V_2]$

$\therefore \frac{V_3}{V_2} = \frac{1050}{350} = 3$.

$\therefore W_{net} = R \times 1050 \ln 3 + 1 \times R(350 - 1050)$.

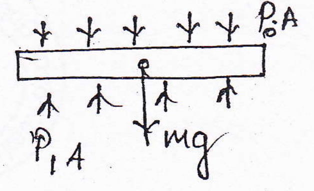
$= 453{\cdot}4\,J$.

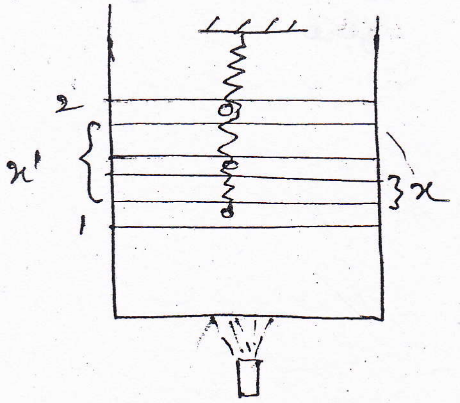
(93) sol) $V_1 = 0{\cdot}05\,m^3$, $P_1 = 200\,kPa$, $k = 150\,kN/m$,

$V_2 = 2V_1 = 0\cdot$[illegible]$1\,m^3$.

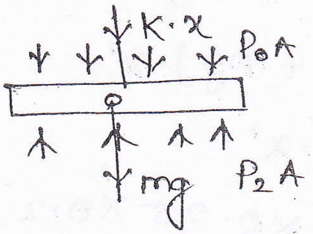
$A = 0{\cdot}25\,m^2$.

F·B·D





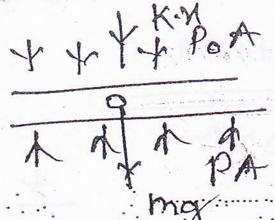
$$P_1 A = mg + P_0 A$$



$$P_2 A = P_0 A + mg + K\cdot x'$$

$$\Rightarrow \boxed{P_2 A = P_1 A + K\cdot x'} \longleftarrow (II)$$

F.B.D in b/w the two positions



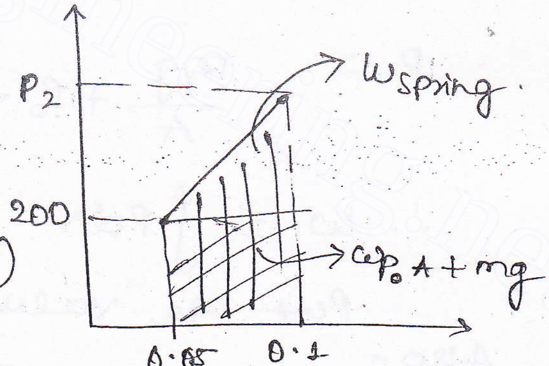
$$P\cdot A = mg + P_0 A + K\cdot x$$

$$\Rightarrow \boxed{P\cdot A = P_1\cdot A + K\cdot x} — (I)$$

Also, $V - V_1 = A\cdot x \Rightarrow x = \frac{V - V_1}{A}$

Putting the value of x in (I)

$$P\cdot A = P_1 A + K\left(\frac{V - V_1}{A}\right)$$



$$P \propto V$$

$$W = \frac{1}{2}(P_1 + P_2) \times (V_2 - V_1)$$

$$P_2 = \frac{1}{A}\left\{P_1 A + K\cdot x'\right\}.$$ [P_2 from eqn (II)]

$$V_2 - V_1 = A\cdot x'$$

$$x' = \frac{V_2 - V_1}{A} = \frac{0.1 - 0.05}{\frac{\pi}{4}\,0.25}$$

$$\boxed{x' = 0.2}$$

$$\boxed{P_2 = 320\,kPa}$$

$$\therefore W = \frac{1}{2}(200 + 320)(0.1 - 0.05)$$

$$= 13\ KJ.$$

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Alternative

$W_{gas} = W_{P_0A+mg} + W_{spring}$

$W_{P_0A+mg} = (P_0A + mg)\cdot x'$

$= P_1 A \cdot x'$

$= 200 \times 0.25 \times 0.2$

$= 10 KJ.$

$W_{spring} = \frac{1}{2} K [x'^2] - 0 = \frac{1}{2} \times 150 \times (0.2)^2$

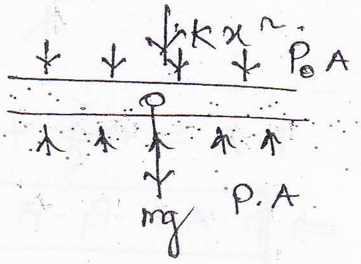
$= 3 kJ$

If spring is not linear.

$PA = mg + P_0A + K\cdot x^2$

$V - V_1 = A\cdot x$

$x = \left(\frac{V-V_1}{A}\right).$



$PA = mg + P_0A + K\left(\frac{V-V_1}{A}\right)^2$

$P = \frac{mg}{A} + P_0 + \frac{K}{A}\left(\frac{V-V_1}{A}\right)^2 \text{ --- (1)}$

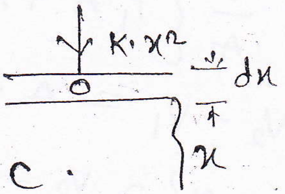
$\therefore W = \int P dV$

Put the value of P from (1).

Also -

$\delta W = -K\cdot x^2 \cdot dx$

$W = \frac{-Kx^3}{3} + C.$



consequence of T.D

(3) Energy of an isolated system is constant

(i) Isolated

closed

A/c to 1st law of thermodynamics the energy of an isolated system remains const. and since universe is an isolated system. Its energy will remain const.

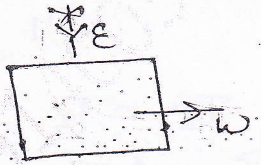
$$\cancelto{0}{\delta Q} = dE + \cancelto{0}{\delta W}$$

$$dE = 0$$

$$\boxed{E = \text{constant}}$$

(4) Perpetual motion machine (1st kind) [PMM 1]

A machine which develops work continuously without absorbing energy in any other form is called PMM1 and is impossible.



- $H = U + \underbrace{PV}$
  - H ↓ Enthalpy
  - PV → Flow work
  - → Flow energy
  - → Displacement work.

$$h = \frac{H}{m} = \frac{U}{m} + \frac{PV}{m}$$

$$\Rightarrow \boxed{h = u + pv}$$

h → specific enthalpy.

In our study of thermodynamics the term U + PV occur very frequently and for convenience it is termed as Enthalpy.

Heat interactions in various processes

(i) constant volume process

Conditions -
- Close
- K.E + P.E is negligible

$$\delta Q = du + \cancelto{0}{dW_b} + \delta W_o$$

0 (for const. vol. process.

$$\underbrace{(\delta Q - \delta W_o)}_{E_v} = du \quad \text{— (A)}$$

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$\varepsilon_v = mC_v dT$ { by def. of C_v, single phase }.

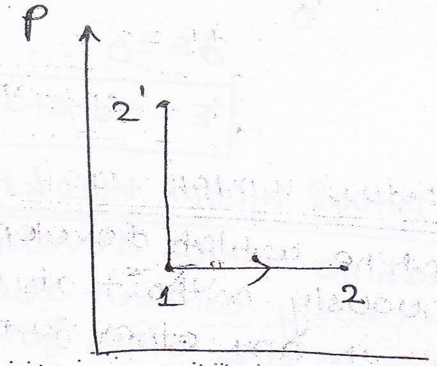
$dU = mC_v dT$

→ const. vol., any substance
or
→ Ideal gas, any process.

$U = f(T)$ only
ideal gas

Ideal

$T_1 \rightarrow T_2$
$U_1 \quad U_2$



$T_{2'} = T_2$

$1-2'$

$(dU) = mC_v dT$
$1-2'$

$U_{2'} - U_1 = mC_v(T_{2'} - T_1)$.

$\because T_2 = T_{2'} \Rightarrow U_2 = U_{2'}$

$U_2 - U_1 = mC_v(T_2 - T_1)$.

In eqn - A

If $\delta W_0 = 0$

$\delta Q = \delta U$.

$$\boxed{(\delta Q)_v = dU}$$

If other is zero heat supplied at const vol. is equal to change in internal energy.

(ii) constant pressure process

Conditions -
- Reversible
- closed
- K.E & P.E negligible.

$\delta Q = dU + PdV + \delta W_0$

$\delta Q - \delta W_0 = dU + PdV$

$= dU + d(PV)$

$= d(U + PV)$

$$\underbrace{\delta Q - \delta W_0}_{E_p} = dH$$

$E_p = mC_p dT$ [By def. of C_p, single phase]

$$\underbrace{dH = mC_p dT}$$

→ const. press., any substance.

→ Ideal gas, any process.

If $\delta W_0 = 0$

$$\boxed{(\delta Q)_p = dH}$$

Ideal gas

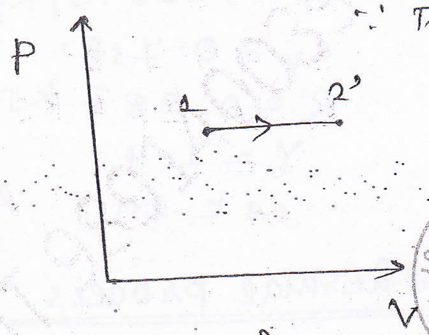
$U = f(T)$ only

$H = U + PV$

$= U + mRT$

$H = f(T)$ only

$H_{2'} = H_2$, $\because T_{2'} = T_2$.



$T_2 = T_2'$

$(dH)_{1-2'} = mC_p(dT)_{1-2'} = mC_p(T_{2'} - T_1)$

$H_{2'} - H_1 = mC_p(T_{2'} - T_1)$

$H_2 - H_1 = mC_p(T_2 - T_1)$.

If other work is zero heat supplied at constant pressure is equal to change in enthalpy.

To prove $(C_p - C_v = R)$ for ideal gas

$H = U + PV$

For ~~It~~ ~~is~~ an ideal gas

~~Hence~~ $PV = mRT$

$\therefore dH = dU + ~~Pdv~~ d(mRT)$

$dH = dU + mRdT$

$mC_p dT = mC_v dT + mRdT$

$C_p = C_v + R$.

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$$\boxed{C_p - C_v = R} \rightarrow \text{Meyer's eqn.} \quad \rightarrow \text{ideal gas}$$

$$\gamma = \frac{C_p}{C_v}$$

$$C_p = \gamma C_v$$

$$\gamma C_v - C_v = R$$

$$\Rightarrow \boxed{C_v = \frac{R}{\gamma - 1}}, \quad \boxed{C_p = \frac{\gamma R}{\gamma - 1}}$$

Air

$C_p = 1.005$ kJ/kg-K.

$C_v = 0.718$

$R = 0.287$ kJ/kg-K.

$\gamma = 1.4$

$M = 29$, $R = \frac{\bar{R}}{29} = \frac{8.314}{29} = 0.2866$

Isothermal process

$$\delta Q = du + \delta W$$

Ideal gas

$$\delta Q = \cancel{mc_v dT} + \delta W$$

=0 (for isothermal process)

$$\boxed{\delta Q = \delta W}$$

conditions
- close system
- stationary system
- K.E & P.E → Negligible.

Adiabatic process

$(\delta Q = 0)$

$$\delta Q = du + \delta w$$

$$\boxed{\delta w = -du}$$

Polytropic process

$$\boxed{pv^n = const}$$

$$\delta Q = du + Pdv$$

$$Q = U_2 - U_1 + \frac{P_1V_1 - P_2V_2}{n-1}$$

Assumptions
- Closed system.
- Quasistatic
- P.E & K.E negligible.
- Reversible,
- other work $\delta w_o = 0$

Ideal gas

$$q = mC_v(T_2 - T_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

For an ideal gas
$mRT_2 - mRT_1$
$= P_2V_2 - P_1V_1$

$$q = m\frac{R}{\gamma-1}(T_2 - T_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$q = \cancel{m}\frac{\cancel{R}}{\cancel{\gamma-1}}\frac{(P_2V_2 - P_1V_1)}{\gamma-1} + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$q_p = \underbrace{\boxed{\frac{P_1V_1 - P_2V_2}{n-1}}}_{\Downarrow\, w_p}\left\{-\frac{n-1}{\gamma-1} + 1\right\}.$$

$$q_p = w_p \times \left\{1 - \frac{n-1}{\gamma-1}\right\}.$$

[w_p = work done in polytropic process]

$$= w_p\left\{\frac{\gamma-1-n+1}{\gamma-1}\right\}.$$

$$\boxed{q_p = (w_p) \times \frac{\gamma-n}{\gamma-1}}$$

Polytropic specific heat

$$\delta q = du + Pdv$$

Ideal

$$q = \underbrace{\boxed{U_2 - U_1}}_{\Downarrow\, mC_v(T_2-T_1)} + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$q = m\frac{R}{\gamma-1}(T_2 - T_1) + \frac{mR(T_1 - T_2)}{n-1}$$

$$q = m(T_2 - T_1)\left\{\frac{R}{\gamma-1} - \frac{R}{n-1}\right\}$$

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$$= m(T_2-T_1)\times\frac{R}{\gamma-1}\left\{1-\frac{\gamma-1}{n-1}\right\}$$

$$q = m(T_2-T_1)\times C_v\left\{\frac{n-1-\gamma+1}{n-1}\right\}$$

$$q = m(T_2-T_1)\underbrace{\boxed{\left\{C_v\,\frac{n-\gamma}{n-1}\right\}}}_{C_{polytropic}\text{ (specific heat of polytropic)}}$$

Also

$\gamma = 1.4$, $pV^{1.3} \rightarrow n = 1.3$

$$C_{poly} = C_v\left(\frac{1.3-1.4}{1.3-1}\right) = -ve$$

$$q_p = W_p \times \frac{\gamma-n}{\gamma-1}$$

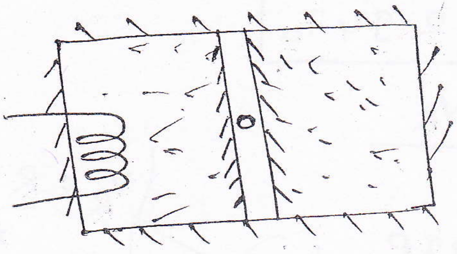
$$10 = W_p \times\left(\frac{1.4-1.3}{1.4-1}\right)$$

$$W_p = 40\,kJ$$

Supplying only 10kJ heat but 40kJ work is done because some energy is in form of internal energy.

The polytropic specific heat is -ve i.e, eventhough heat is supplied, the temp. of the fluid decreases because work done by the fluid exceeds heat supplied.

⑧ A rectangular box as shown in diagram as a partition which slides without friction along the length of the box. Initially the two chambers contain 1kg each of an ideal gas ($\gamma = 5/3$) and P_0, V_0, T_0. The chamber on the left is slowly heated by an electric heater. The walls of the box and the partition are thermally insulated. The gas in the left chamber expands pushing the partition until the final pressure in both the chambers is $\frac{243 P_0}{32}$. Determine the final temp. of gas in each chamber and work done by gas in the right chamber in terms of P_0, T_0, V_0.



Initially – T_L, P_L, V_L.
Finally – T_R, P_R, V_R.

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Sol:- $m = 1\,Kg$, $\gamma = 5/3$, $P_R = \frac{243 P_0}{32}$,

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$\Rightarrow \cancel{P_0} V_0^{\gamma} = \frac{243 \cancel{P_0}}{32} \times V_2^{\gamma} \Rightarrow \left(\frac{V_0}{V_2}\right)^{\gamma} = \frac{243}{32}$$

$$\delta Q = \delta W + \delta E$$

Left → Polytropic (work is converted into heat and this heat is absorbed).

Right → Adiabatic (Bulk movement of molecules) Heat in form of work is absorbed.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$$

$$\frac{T_R}{T_0} = \left(\frac{\frac{243 P_0}{32}}{P_0}\right)^{\frac{5/3-1}{5/3}}$$

$$\boxed{T_R = 2.25\,T_0}$$

$$V_L + V_R = 2V_0$$

$$\frac{\cancel{R}T_L}{P_L} + \frac{\cancel{R}T_R}{P_R} = \frac{2\times\cancel{R}T_0}{P_0} \quad \left[\begin{array}{l} PV = mRT \\ \text{where } m=1 \end{array}\right]$$

$$\Rightarrow T_L + T_R = \left(\frac{243\cancel{P_0}}{32}\right) \times \frac{2T_0}{\cancel{P_0}}$$

where $T_R = 2.25\,T_0$.

$$\Rightarrow T_L + 2.25\,T_0 = \left(\frac{243}{32}\right) \times 2T_0 .$$

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$$\boxed{T_L = 12.94\,T_0}$$

$$w = \frac{P_0V_0 - P_R \cdot V_R}{\gamma - 1}$$

$$w = \frac{P_0V_0 - \frac{243P_0}{32} \times V_R}{\frac{5}{3} - 1}$$

$$V_R = \frac{RT_R}{P_R}$$

$$V_R = \frac{R \times 2.25\,T_0}{\left(\frac{243P_0}{32}\right)}$$

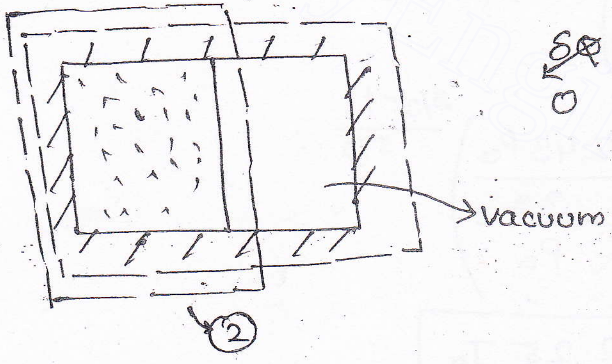
$$\boxed{w = -1.87\,P_0V_0}$$

Because work is done on the system.

when both container and its contents is taken as system then energy is transfered in the form of work.

Free expansion

Other work → shaft or electrical energy.



$$\underset{0}{\cancel{\delta Q}} = du + \cancel{dw}^{\,0}$$

$du = 0$

$u_i = u_f$

ideal gas

$(U = f(T)$ only$)$

$T_i = T_f$.

Here, work done = 0 boundary work done + other work done.

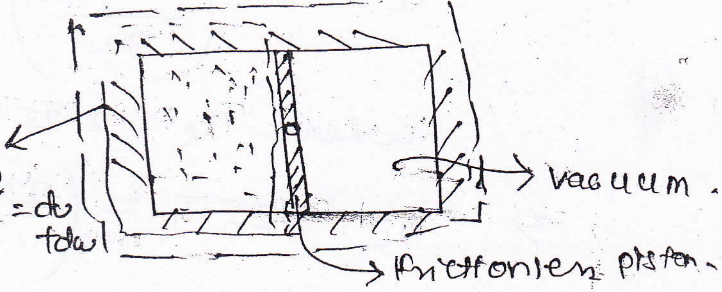
No internal energy change from initial to final, as initially the molecules of gases are moving and internal energy of molecules converted into K.E energy and at last ~~into~~ K.E is converted into Internal energy. Thus, the net effect remains same.

(2) $\cancel{\delta Q}^{0} = du + dw$

$$\underset{0}{\cancel{\delta Q}} = du + \cancel{dw}^{\,0}$$

$du = 0$.

② $\underset{=0}{\cancel{\delta Q}} = dw + du$.



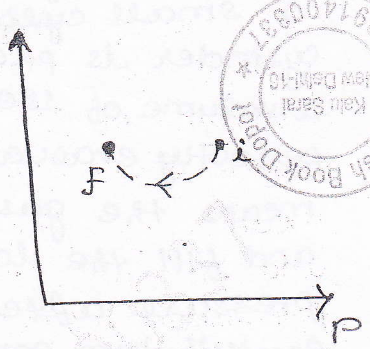
In the free expansion initial and final internal energies are const. but the internal energy decreases in between the initial and final pts.
If the gas is an ideal gas then the initial and final temperatures will be same but the temp. anywhere in between will be less than initial and final temp.

Ideal

$$PV = mRT$$

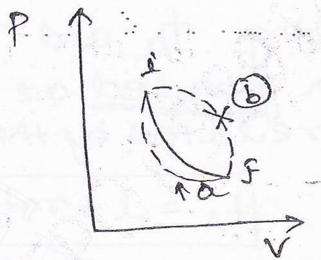
$$\frac{PV}{T} = const$$

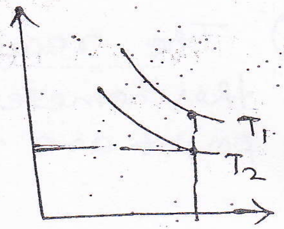
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$



$$\therefore T_1 = T_2$$

$$P_1V_1 = P_2V_2$$





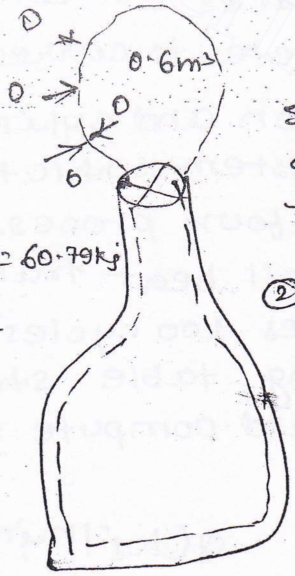
(3.3) When the valve of the evacuated bottle is opened, atmosphere air rushes into it. If Patm = 101.325 KPa & 0.6 m³ of air enters in the bottle, calculate W-D by air.

Ans

When outside air is taken as system

$$W_0 = P_0 \times V$$

$$= 101.325\ KPa \times 0.6\ m^3 = 60.79\ kJ$$



So, the W.D depends on the system taken.

② Boundary is moving in opp. dirn w.r.t to air molecules the W.D = -ve.

② When the system inside the boundary is taken as system then

$$W_0 = -60.79\ kJ$$

When the outside air and inside system ~~is~~ both is taken as system and this is the case of free expansion i.e, no boundary

$$W_{i+o} = 0$$

If boundary is taken inside the given bottle and evacuated with the help of piston thus this is not a case of free expansion.

P.K Nag) unsolved :- 3.9
solved :- 4.3

(Q)(1) An ideal gas at 20 bar and 40°C is contained in a small cylinder having a vol of 15 cm^3. This cylinder is placed in a large container having a volume of 1500 cm^3. The large container is perfectly evacuated and insulated by an appropriate means the gas is allowed to expand freely and fill the large container. Find the final pressure after the entire assembly reaches equillibrium condition.

(2) The reading t_A and t_B for a centigrade thermometer graded at ice point and steam point are related by the equation

$$\boxed{t_A = l + m t_B + n t_B^2}$$

where n, l and m are constants. when both are immersed in air, A reads 51°C and B reads 50°C. Determine the reading A when B reads 25°C. Comment on the question "which thermometer is correct".

(4.3) A piston and cylinder machine contains a fluid system which passes through a complete cycle of four processes. During a cycle, the sum of all heat transfers is −170 kJ. The system completes 100 cycles per min. complete the following table showing the method for each item, and compute the net rate of work output in kW.

Process	Q(kJ/min)	W(kJ/min)	ΔE(kJ/min)
a−b	0	2170	—
b−c	21000	0	—
c−d	−2100	—	−36600
d−a	—	—	—

Sol Process a-b.

$\delta Q = \delta W + \Delta E$

$\Rightarrow 0 = 2170 + \Delta E$

$\Rightarrow \boxed{\Delta E = -2170 \text{ kJ/min}}$.

Process b-c

$21000 = 0 + \Delta E$

$\Rightarrow \boxed{\Delta E = 21000 \text{ kJ/min}}$

Process c-d

$-2100 = W - 36600$

$\Rightarrow \boxed{W = 34500 \text{ kJ/min}}$.

Given,

$\Sigma Q = -170 \text{ kJ}$.

There are 100 cycle/min.

$\therefore \Sigma Q$ for all cycles $= -17000$ kJ.

$\therefore 0 + 21000 + (-2100) + Q_{d-a} = -17000$

$\Rightarrow \boxed{Q_{d-a} = -35900 \text{ kJ/min}}$

A/c Ist law of T.D

$\Sigma Q = \Sigma W$.

$\therefore -17000 = 2170 + 0 + 34500 + W_{da}$

$\Rightarrow W_{d-a} = -53670 \text{ kJ/min}$.

$Q = W + \Delta E$

$\Rightarrow \Delta E = -35900 + 53670$

$\Rightarrow \Delta E = 17770$

$\Sigma Q = \Sigma W = -17000 \text{ kJ/min}$

$= -17000/60 = 283.3 \text{ kW}$.

14	11	13

(2) when thermometers are graded

$$t_A = t_B = 0$$

$$t_A = l + m t_B + n t_B^2$$

$$0 = l + m(0) + n(0)$$

$$l = 0$$

$$\overset{c_1}{100} = 0 + m\overset{a_1}{(100)} + n\overset{b_1}{(100)^2}$$

$$\overset{c_2}{51} = 0 + m\overset{a_2}{(50)} + n\overset{b_2}{(50)^2}$$

In calci

MODE → 3rd

EQN → 1

$\boxed{\text{for degree Right side.}}$

= Put the value of a_1

then =

$b_1 =$

$c_1 =$

Similarly

$a_2 \Rightarrow b_2 \Rightarrow c_2 = \Rightarrow$

= then press equal to after each value.

$$m = 1.04$$

$$n = -4 \times 10^{-4}$$

$$t_A = 0 + 1.04(25) - 4 \times 10^{-4}(25)^2.$$

Q(1) In free expansion

work = 0

Adiabatic also, Heat transfer = 0.

Initial = final internal energy.

$$\boxed{u_1 = u_2}$$

Ideal gas

$$T_1 = T_2.$$

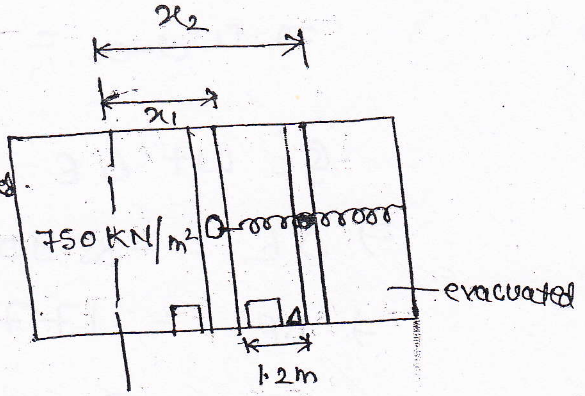
$$P_1 V_1 = P_2 V_2.$$

$$\Rightarrow 20 \times 15 = P_2(1500).$$

$$\Rightarrow \boxed{P_2 = 0.2 \text{ bar}}$$

P.k nag

(3.9) $f_1 = 120N$ Assuming spring is compressed.



After displacement

$F_2 = 5000 N.$

$$W = \frac{1}{2}Kx_2^2 - \frac{1}{2}Kx_1^2$$

$$f_1 = K \cdot x_1 \quad \Rightarrow 120 = K x_1$$

$f_2 = k \cdot x_2 \Rightarrow 5000 = k \cdot x_2$

$x_2 - x_1 = 1.2$

$\Rightarrow -\frac{120}{k} + \frac{5000}{k} = 1.2$

$\Rightarrow k = 4066.6$ N/m.

$x_1 = \frac{120}{4066.6} = 0.0295$ m.

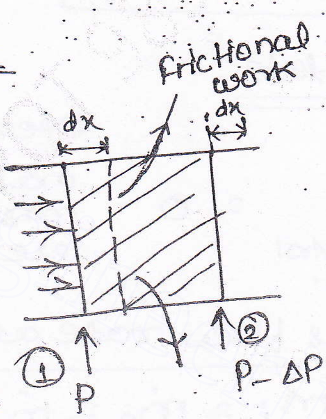
$x_2 = \frac{5000}{4066.6} = 1.229$ m.

$W = \frac{1}{2} \times 4066.6\,(1.229^2 - 0.0295^2) =$

$= 3069.4\,J = 3.06\,kJ$.

Open system Analysis

Displacement work



Work done at inlet

$W = PA \times dx$.

Work done at exit

$W = (P - \Delta P) \cdot A \cdot dx$

Decrease in work is due to some frictional work.

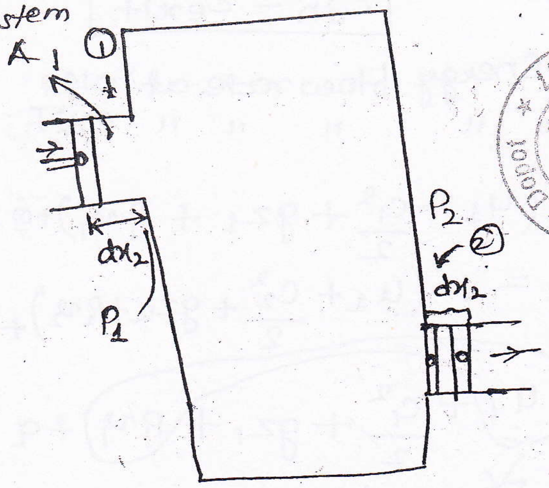
(work is done on the system thus −ve)

$\delta W = -P_1 \underbrace{A_1 \cdot dx_1}_{dV_1}$

(swept vol.)

$\delta W = P_2 \cdot \underbrace{A_2 \cdot dx_2}_{V_2}$

$= P_2\, dV_2$.



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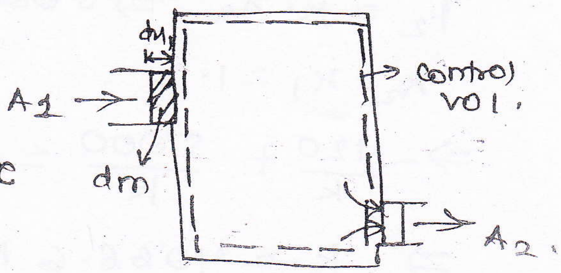
At Entry

$$\delta w_1 = -P_1 \cdot A_1 \cdot dx_1$$

$$\frac{\delta w_1}{dm} = -P_1 \underbrace{\frac{dv_1}{dm}}_{\text{specific vol.}}$$



$$\boxed{\frac{\delta w_1}{dm} = -P_1 v_1}$$

At exit

$$\delta w = +P_2 A_2 \cdot dx_2$$

$$\frac{\delta w}{\delta m} = P_2 \cdot \underbrace{\frac{dv_2}{dm}}_{\text{specific vol.}}$$

$$\boxed{\frac{\delta w}{\delta m} = P_2 v_2}$$

Steady state

$$\left(\frac{dm}{dt}\right)_{\text{control vol.}} = 0$$

Steady state means change in mass w.r.t time is zero then mass flow rate at inlet and exit are same.

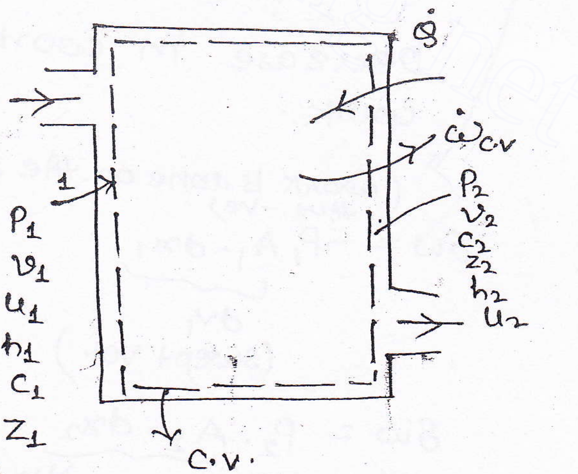
Mass flow rate at inlet = Mass flow rate at exit

$$\boxed{\dot{m}_i = \dot{m}_e = \dot{m}}$$

conservation of Energy

$$\boxed{\dot{E}_{in} = \dot{E}_{exit}}$$

Energy flow rate at Inlet
= " " " " exit.



$$\dot{m}\left(u_1 + \frac{c_1^2}{2} + gz_1 + P_1 v_1\right) + \dot{Q}$$

$$= \dot{m}\left(u_1 + \frac{c_2^2}{2} + gz_2 + P_2 v_2\right) + \dot{w}_{c.v}$$

$$u_1 + \frac{c_1^2}{2} + gz_1 + P_1 v_1 + q = u_2 + \frac{c_2^2}{2} + gz_2 + P_2 v_2 + w_{cv}.$$

enthalpy h_1.

enthalpy h_2.

$$\boxed{h_1+\frac{c_1^2}{2}+gz_1+q=h_2+\frac{c_2^2}{2}+gz_2+\omega_{c.v}}$$

$$\frac{\dot{Q}}{\dot{m}}=q,\quad \frac{\dot{\omega}_{c.v}}{\dot{m}}=\omega_{c.v}\qquad \left[\begin{array}{l} Q\ \text{kJ/sec} / \dot{m}\ \text{kg/sec} \\ q=\text{kJ/sec} \end{array}\right.$$

- Control volume work is also called shaft work in open system.

(1) For steady state (Steady flow energy eqn)

$$\boxed{h_1+\frac{c_1^2}{2}+gz_1+q=h_2+\frac{c_2^2}{2}+gz_2+\omega_{c.v}}$$

(2) when $\Delta K\cdot E=0$ & $\Delta P\cdot E=0$ (First law of T.D for an open system under steady state when K.E & P.E = 0)

$$\boxed{h_1+q=h_2+\omega_{c.v}} \quad \text{—— (I)}$$

Also,

$$H_2-H_1=(U_2+P\cdot V_2)-(U_1+PV_1)$$
$$=(U_2-U_1)+P(V_2-V_1)$$

from (I), $q=(h_2-h_1)+\omega_{c.v}$

$$\boxed{\delta q=dh+(\delta\omega)_{c.v}} \quad \text{—— (II)}$$

$$\delta q=\underbrace{du+\delta\omega_b}_{dh}+\underbrace{\delta\omega_o}_{\substack{\text{other work}\\ \text{similar to }(\delta\omega)_{c.v}\\ \text{from eq (II)}}} \quad \text{—— (III)}$$

Comparing (II) & (III)

$$\boxed{du+\delta\omega_b=dh}$$

$$\boxed{\delta\omega_o=(\delta\omega)_{c.v}}$$

$$* \quad \boxed{h_1+\frac{c_1^2}{2}+gz_1+q=h_2+\frac{c_2^2}{2}+gz_2+\omega_{c.v}}$$

It is the first law of thermodynamics for an open system working under steady state.

① Steady state

$$u_1 + P_1 v_1 + \frac{c_1^2}{2} + gz_1 + q = u_2 + P_2 v_2 + \frac{c_2^2}{2} + gz_2 + w_{c.v}$$

② $q = 0$ & $w_{c.v} = 0$

③ $u_1 = u_2$

$$P_1 v_1 + \frac{c_1^2}{2} + gz_1 = P_2 v_2 + \frac{c_2^2}{2} + gz_2$$

$$\frac{P_1}{\rho_1} + \frac{c_1^2}{2} + gz_1 + \frac{P_2}{\rho_2} + \frac{c_2^2}{2} + gz_2$$

④ Incompressible

$$\boxed{\rho_1 = \rho_2}$$

$$\boxed{\frac{P_1}{\rho g} + \frac{c_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{c_2^2}{2g} + z_2} \quad \{\text{Energy/wt}\}$$

Bernoulli's eqn.

Incompressible Substances

① Internal energy

For incompressible substance volume remains const.

If other work is not present in incompressible thus boundary work is also zero. Then all energy get converted into internal energy.

$$du = mc_v dT$$

$$du = mc\,dT$$

Incompressible

$$\boxed{C_p \simeq C_v = C}$$

① $T = 0$ $\quad U_0 = 0$ $\qquad du = mc\,dT$

② $T = T$ $\quad U = U$ $\qquad U - 0 = mc(T - 0)$

$$\boxed{U = mcT}$$ when the substance is incompressible.

For enthalpy

Always remember, $\boxed{h = u + Pv}$

Steady flow energy equation (SFEE) applied to various devices

$$h_1 + \frac{C_1^2}{2} + gz_1 + q = h_2 + \frac{C_2^2}{2} + gz_2 + w_{c.v}$$

(1) Nozzle

Assumptions

(1) Steady state (2) Adiabatic $(q=0)$

(3) $\Delta P.E = 0$ (4) $w_{c.v} = 0$ (5) $C_1 << C_2$ $h_1 = h_2 + \frac{C_2^2}{2}$

$$\boxed{C_2 = \sqrt{2(h_1 - h_2)}}$$

SFEE for Nozzle $\boxed{h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}}$

Nozzle - 15-20cm

(2) Turbine

Assumptions

(i) steady state (ii) Adiabatic $(q=0)$

(iii) $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\boxed{w_{c.v} = h_1 - h_2}$$

(3) compressor

Assumptions

(i) steady state (ii) Adiabatic $(q=0)$

(iii) $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\boxed{w_{c.v} = h_1 - h_2}$$

$$\boxed{w_{I/P} = h_2 - h_1}$$ I/P → Input

Throttling device

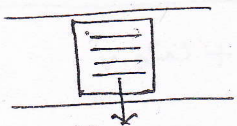
(i) Capillary tube

- Domestic refrigeratorator
- Window A/C.

(ii) Partially opened valve

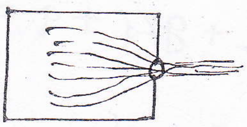
- Tap.

(iii) Porous plug



(iv) Flow through small orifice

Eg:- deodrant



SFEE for throttling

$$h_1 + \frac{c_1^2}{2} + gz_1 + q = h_2 + \frac{c_2^2}{2} + gz_2 + w_{c.v}$$

Assumptions

(i) steady state.

(ii) $\Delta K.E = 0$ & $\Delta P.E = 0$

(iii) $q = 0$ & $w_{c.v} = 0$

SFEE $\boxed{h_1 = h_2}$

Throttling process is highly quasistatic or irreversible.

Characteristic of Throttling process

(i) Isenthalpic.

(ii) $w_{cv} = 0$

(iii) Highly irreversible.

(iv) Adiabatic.

Gate'10 ⑧ A monoatomic $\overset{MRT}{\text{ideal gas}}$ ($\gamma = 1.67$), molecular wt. = 40 is compressed adiabatically from 0.1 MPa, 300K to 0.2 MPa. The universal gas const. $R = 8.314$ kJ/kg-mol K. The work of compressor of the gas in kJ/kg is

⑧ Sol $P_1 V_1^\gamma = P_2 V_2^\gamma$.

$$\bar{R} = \frac{8.314}{40} = 0.207$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma - 1/\gamma}$$

$$\Rightarrow \frac{T_2}{300} = \left(\frac{0.2}{0.1}\right)^{0.67/1.67}$$

$\Rightarrow T_2 = 396.18 \ K.$

$$w = \frac{P_1 v_1 - P_2 v_2}{\gamma - 1}$$

$$= \frac{mR(T_1 - T_2)}{0.67}$$

$$= \frac{0.207(-396.18 + 300)}{0.67}$$

$$= -29.71 \ KJ/Kg.$$

Remember

$\int P dv$
① closed
⑪ Quasistatic.

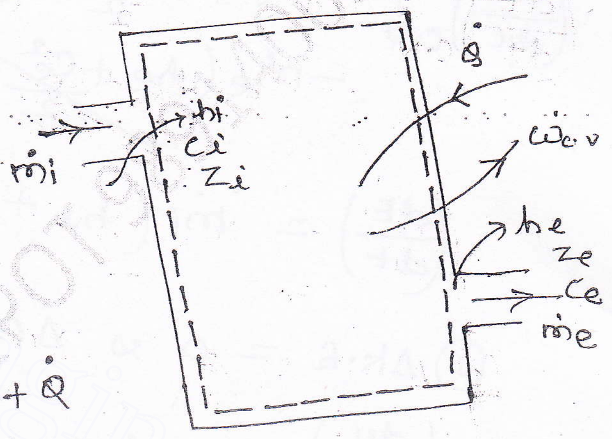
PV^γ
① Adiabatic
② Reversible.
③ Ideal.

$\frac{m}{M}$

unsteady state

(1) conservation of Mass

$$\left(\frac{dm}{dt}\right)_{c.v} = \dot{m}_i - \dot{m}_e$$



(2) conservation of Energy

$$\left(\frac{dE}{dt}\right)_{c.v} = \dot{m}_i\left(h_i + \frac{C_i^2}{2} + gz_i\right) + \dot{Q} - \dot{m}_e\left(h_e + \frac{C_e^2}{2} + gz_e\right) - \dot{W}_{c.v}$$

(3) $\Delta K.E = 0 \quad \Delta P.E = 0$

$$\left(\frac{dE}{dt}\right)_{c.v} = \left(\frac{du}{dt}\right)_{c.v}.$$

$$\boxed{\left(\frac{du}{dt}\right)_{c.v} = \dot{m}_i h_i + \dot{Q} - \dot{m}_e h_e - \dot{W}_{c.v.}}$$

⑧ An insulated storage tank i.e, initially evacuated is connected to supply line carrying a fluid at specific internal energy u_i and specific enthalpy h_i. The valve is open and the fluid flows into the tank from the supply line and reaches a pressure same as that of supply line. Show that the final

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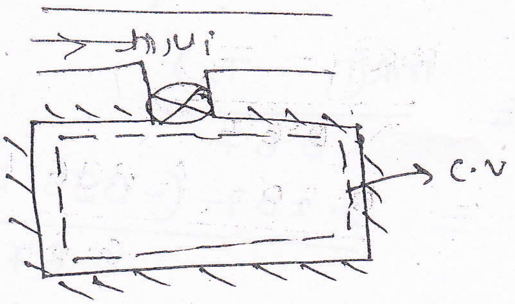
Specific internal energy of the fluid in the tank = h_i.

Sol:- No Mass flow rate at exit thus

$$\left(\frac{dm}{dt}\right)_{C.V} = \dot{m}_i - \cancelto{0}{\dot{m}_e}$$

$$= \dot{m}_i$$



As no. mass flow rate takes place at exit thus,

$$\left(\frac{dE}{dt}\right)_{C.V} = \dot{m}_i\left(h_i + \frac{C_i^2}{2} + gz_i\right) + \dot{Q}$$

$$-\dot{m}_e\left(\cancelto{0}{h_e + \frac{C_e^2}{2} + gz_e}\right) - \cancelto{0}{\dot{W}_{C.V}}$$

$$\left(\frac{dE}{dt}\right) = \dot{m}_i\left(h_i + \frac{C_i^2}{2} + gz_i\right)$$

① $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\left(\frac{du}{dt}\right)_{C.V} = \dot{m}_i h_i = \left(\frac{dm}{dt}\right) h_i$$

$$\int_1^2 du = \int_1^2 \left(\frac{dm}{dt}\right) h_i \, dt$$

(2) h_i = const

$$u_2 - u_1 = h_i \int_1^2 \frac{dm}{\cancel{dt}} \times \cancel{dt}$$

$$m_2 u_2 - \cancelto{0}{m_1 u_1} = h_i\left(m_2 - \cancelto{0}{m_1}\right)$$

$$\cancel{m_2} u_2 = h_i \cancel{m_2}$$

$$\boxed{u_2 = h_i}$$

$$\left\{\begin{array}{c} \underbrace{U_2}_{h_i} > U_i \\ u_i + P_i v_i > u_i \end{array}\right\}$$

For an ideal gas

$$C_v T_2 = C_p T_i$$

$$\boxed{T_2 = \gamma T_i}$$

Air, $\gamma = 1.4$

$T_i = 300K$

$T_2 = 1.4 \times 300 = 420K$

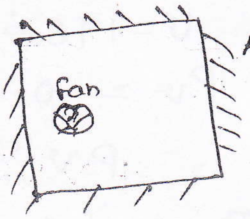
W.B ① $w = c \ln\left(\frac{V_2}{V_1}\right)$

$$-206 = n\bar{R}T \ln\left(\frac{V_2}{V_1}\right)$$

$$\boxed{V_1 = \cancel{70}\ \cancel{2}\ e \cdot V_2}$$

(2) $W = RT_0 \ln \frac{P_0}{P_1} = -RT \ln\left(\frac{P_1}{P_0}\right)$

(3) Energy entered in room in the form of work.



$\delta Q = du + \delta w$

Gas $\delta w = -du$

$= -mc_v(T_2 - T_1)$ thus $-ve$

we have supplied work -60×10^{-3} kJ/sec

$\therefore w = -60 \times 10^{-3}$

$$-60 \times 10^{-3} \times 4 \times 3600 = \frac{-100 \times 86.4 \times dT}{0.287 \times (273+32)}$$

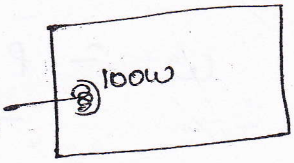
$\times$ $(0.718)C_v$

$\Rightarrow dT = 12.19°c$

(5) one clockwise, one anticlockwise.

(14)(c) when ice melts its vol. decreases, work done on system. Thus $w = -ve$, $Q = +ve$

(15) $100W - 100 J/S$.

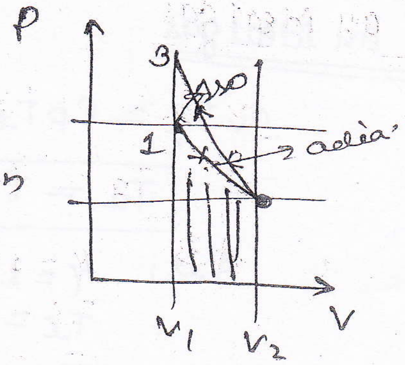


100×10^{-3} KJ/S $\cancel{8} \times 30$ min $\times \cancel{3}60 = mC_v dT$

$= 30 \times 0.7 (T_2 - 21)$

(16) vol^m ↑ → Work done by the system.

vol^m ↓ → work done on the system.



15	11	13

P.K Nag (4.15)

$$C_p = 2.093 + \frac{41.87}{t+100}\ \text{J}/^\circ\text{C}.$$

$$Q_p = \int_0^{100} C_p\,dt = 238.32\ \text{J}.$$

$$W = \int P\,dV = 101.325\,\text{N/m}^2\,(2400-2000)\times10^{-6}\,\text{m}^3 \times 10^3$$

$$= 0.0405\ \text{kJ} = 40.5\ \text{J}.$$

$$\delta Q = du + \delta W$$

$$du = \delta Q - \delta W \Rightarrow du = 238.32 - 40.5 = 197.79 \ \text{J}.$$

(4.11) $U = 196 + 0.718t$

$$Pv = 0.287\,(t+273)$$

$$Pv^{1.2} = \text{const}.$$

$Q = 0$ (As the process is adiabatic)

$$\delta W = -du$$

$$= -(U_2 - U_1) = U_1 - U_2$$

$$= 2(U_1 - U_2) = 2\times0.718(t_1 - t_2).$$

$$P_1 v_2 = 0.287\,(t_2 + 273)$$

$$t_2 = 49.125^\circ\text{C}.$$

$$W = 2\times0.718\,(t_1 - t_2)$$

$$= 216.25\ \text{KJ}$$ (Actual work done)

Also,

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$W = \frac{P_1v_1 - P_2v_2}{0.2} \Rightarrow W_T = 2\times W$$

$$= 432.65\ \text{kJ}$$

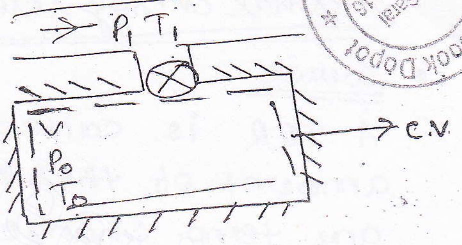
Adiabatic, Reversible, ideal then only $T_2/T_1 = (P_2/P_1)^{\gamma-1/\gamma}$ is used.

Here, average pressure > pressure ~~too~~ close to piston as the process is expansion process.

- Actual pressure is pressure close to piston and ~~p~~ work done is calculated on this basis the ω is less than ω_T.
- If the expansion process is quasi-static then max^m work is obtained.
- quasi-static expansion and compression are most efficient process.
- work required during compression is minimum if the process is quasi-static and work obtained from expansion process is maxm is if process is quasistatic.

(5.20) Assumed that the container is insulated

$$\left(\frac{dm}{dt}\right)_{C.V} = \dot{m}_i - \cancel{\dot{m}_e}^{\,0} = \dot{m}_i$$



$$\left(\frac{dE}{dt}\right)_{C.V} = \dot{m}_i\left(h_i + \frac{C_i^2}{2} + gz_i\right) + \cancel{\dot{Q}}^{\,0}$$

$$- \dot{m}_e\left(h_e + \cancel{\frac{C_e^2}{2} + gz_e}\right)^{0} - \cancel{\dot{W}_{C.V}}^{\,0}$$

(1.) $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\left(\frac{du}{dt}\right)_{C.V} = \frac{dm}{dt}(h_i)$$

(2) h_i = const.

$$\int du = h_i \int \frac{dm}{dt} \times dt$$

$$U_2 - U_1 = h_i(m_2 - m_1)$$

$$\Rightarrow u_2 m_2 - u_1 m_1 = h_i(m_2 - m_1)$$

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$$\Rightarrow C_v \cancel{T} \times \frac{P_1 \cancel{V}}{R \cdot \cancel{T}} - C_v \cancel{T_0} \times \frac{P_0 \cancel{V}}{\cancel{R T_0}} = C_p T_1 \left\{ \frac{P_1 \cancel{V}}{\cancel{R} \cdot T} - \frac{P_0 \cancel{V}}{\cancel{R} \cdot T_0} \right\}$$

$$\Rightarrow P_1 - P_0 = \gamma T_1 \left\{ \frac{P_1}{T} - \frac{P_0}{T_0} \right)$$

$$\Rightarrow P_1 - P_0 + \frac{\gamma T_1 P_0}{T_0} = \frac{\gamma T_1 P_1}{T}$$

$$\boxed{T = \frac{\gamma T_1 P_1}{P_1 + P_0 \left\{ \frac{\gamma T_1}{T_0} - 1 \right\}}}$$

Second law of thermodynamics

Thermal Energy reservoir (TER)

- **Source**

  A TER is called a source if it can reject large amount of thermal energy without undergoing any temp. change.

- **Sink**

  It is a TER which can absorb large amount of thermal energy without undergoing any temp. change.

IInd law of thermodynamic

According to 2nd law of T.D complete conversion of a low grade energy into high grade energy is impossible in a cycle

low grade energy

It is the random energy or unorganised energy

eg: thermal energy.

High grade energy

It is the organised energy

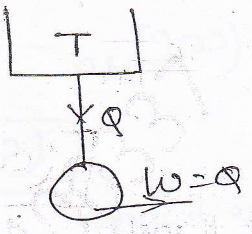
Eg:- work.

Kelvin plank statement for II^nd law of thermodynamics

It is impossible to construct a device working on a cycle which produces work with a single reservoir.

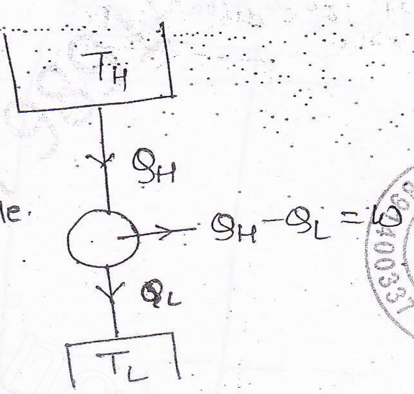
$$\eta = \frac{W}{Q} = \frac{Q}{Q} = 100\%$$ (Not possible)

PMM II



Heat engine

$$\boxed{\eta = \frac{W}{Q_H}}$$ ⇒ valid for reversible as well as irreversible.



- No heat engine can have an efficiency of 100%.
- The heat engines are based on the kelvin plank statement of second law.

Clausius statement of 2nd law

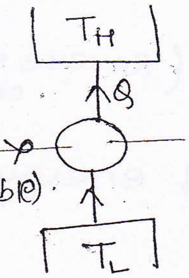
It is impossible to develop a cyclic device which transfers heat from lower temp. to higher temp. without any external energy input.

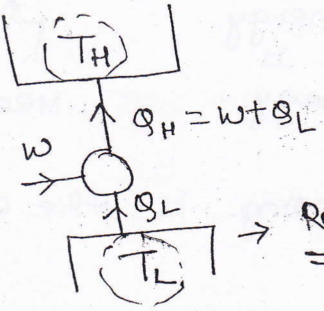
Cop can't be ∞ a/c clausius.

$Cop = \frac{Q}{0}$

$= \infty$

(Not possible).





→ Refrigerator

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$$\boxed{\begin{array}{c} COP \\ \text{or} \\ EPR \\ \text{or} \\ ER \end{array} = \frac{D \cdot E}{E\,I/P}}$$

D.E → Desired effect

E I/P → Energy input

EPR → Energy performance ratio

ER → Energy ratio.

$$(COP)_R = \frac{Q_L}{W}$$

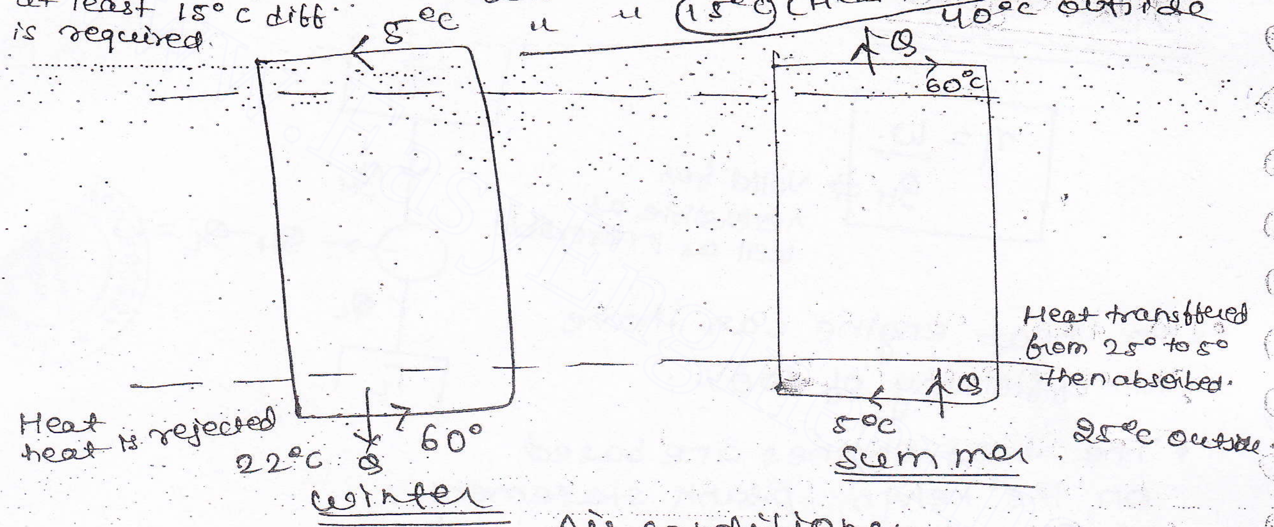
$$(COP)_{HP} = \frac{Q_H}{W}$$

$$(COP)_{HP} - (COP)_R = \frac{Q_H - Q_W}{W} = \frac{W}{W} = 1.$$

$$\boxed{(COP)_{HP} = 1 + (COP)_R}$$

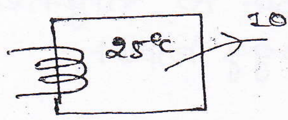
- For Heat transfer at least 15° C diff is required.

outside temp (10°C) (no heat transfer) takes place).
" " (15°C) (Heat transfer


40°C outside
5°C
Q
60°C
Heat is rejected
heat
22°C
Q
60°
Winter
Q
5°C
Heat transffered from 25° to 5° then absorbed.
25°C outside
Summer

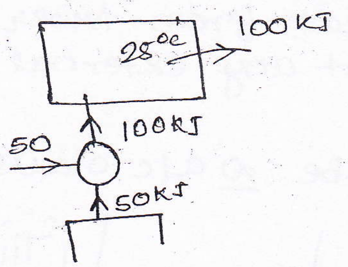
Air conditioner

- Direct heating → waste of energy (Like heater).
- Heat pump - more energy is preserved.



Heater

As direct energy is used, it is waste of energy.

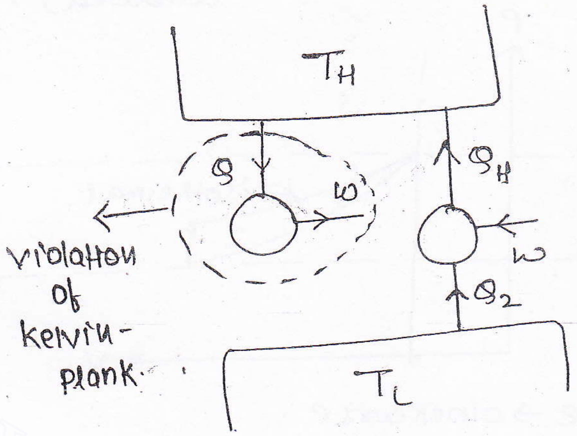

25°C
100KJ
100KJ
50
50KJ

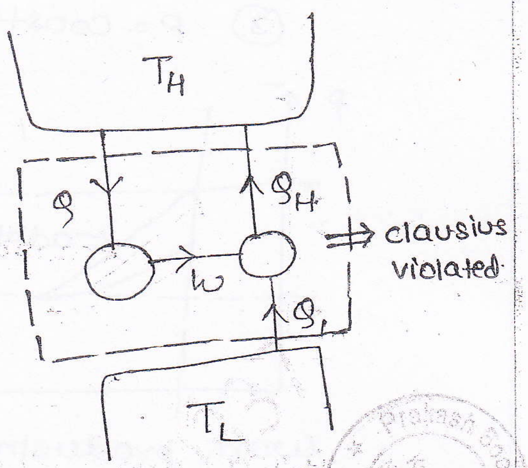
Heat pump (Reverse of Air conditioner)

- Direct heating is the waste of energy.

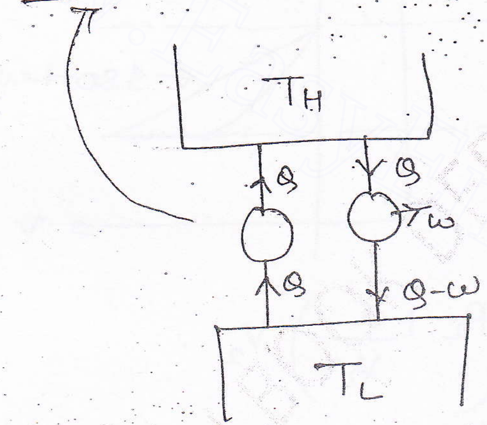
Equivalence of kelvin-plank and clausius statement

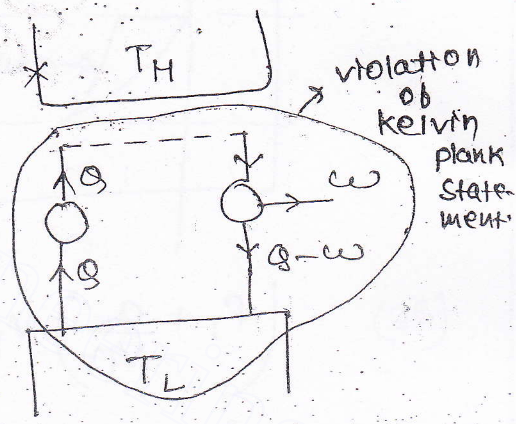
(1) violation of kelvin-plank


T_H
Q
W
Q_H
W
Q_2
violation of kelvin-plank
T_L


T_H
Q
Q_H
W
Q_1
⇒ clausius violated
T_L

(2) violation of clausius

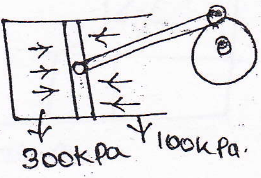

T_H
Q
Q
W
Q
Q-W
T_L


T_H
violation of kelvin plank statement
Q
W
Q
Q-W
T_L

If the clausius statement is violated than it leads to the violation of kelvin plank statement and hence these two statements are known as parallel statements of 2nd law of thermodynamics.

w.B $\boxed{5.17, 5.23, 5.22, 4.14}$

(17)


300KPa
100KPa.

work done by gas
= 300×0.01 = 3KJ.
Force reached to connecting rod = 300-100
= 200KPa.
W_{atm} = 100×0.01 = 1KJ

(20) PV = Const.
PdV = -VdP.

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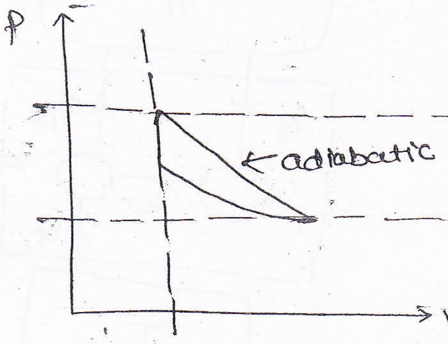
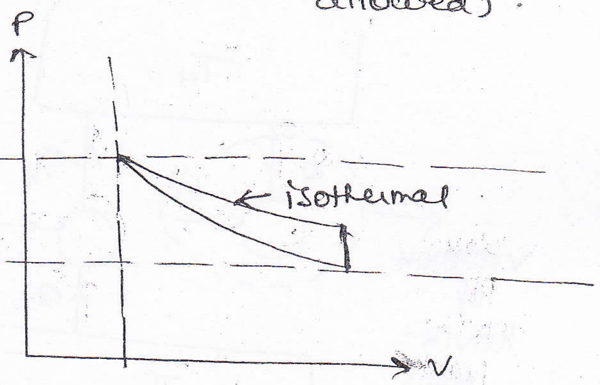
(25) Reversible, Adiabatic – Isentropic

① T = const.

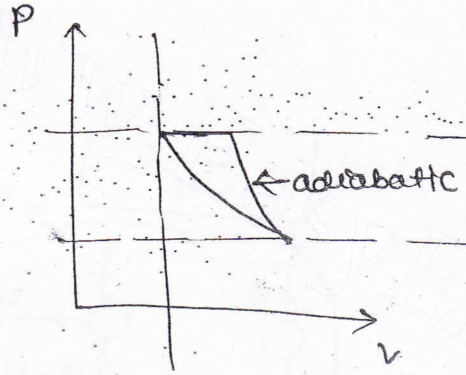
② PV^{γ} = const.

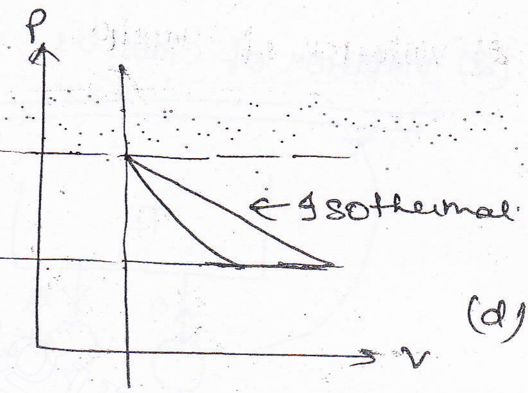
③ P = const. , P = const. (Polytropic not allowed).


P
← adiabatic
V


P
← isothermal
V

Work producing cycle → clockwise.


P
← adiabatic
V


P
← Isothermal
V

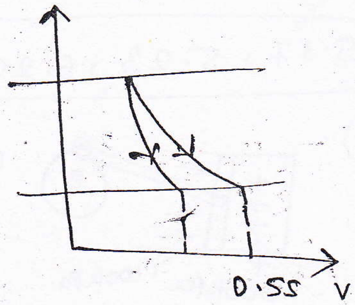
(d)

(26)
$$\left(P_1 + \frac{a}{V_1^2}\right) V_1 = \left(P_2 + \frac{a}{V_2^2}\right) V_2 .$$

$$\left(10 + \frac{a}{1}\right) \times 1 = \left(P_2 + \frac{a}{4}\right) 2$$

$$P_2 = 5 + \frac{a}{2} - \frac{a}{4} = 5 + \frac{a}{4} .$$

(29) Only one value is less than 0.55. then 0.45 is correct.



(36)
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{(Ideal gas)}$$

$$\frac{100 \times 15}{293} = \frac{150 \times 25}{T_2}$$

(37) $w = \int_{15}^{20} P\,dv + \int_{20}^{25} P\,dv$

$= \int_{15}^{20} 100\,dv + \int_{20}^{25} \{ \underset{\downarrow\,100}{P_0} + 2(v - \underset{\downarrow\,20}{v_0})^2 \}\,dv = 1083\ \text{kJ}.$

(38) $V = \text{const}.$

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$, $P_{1(\text{Gauge})}^{(1+1.01)} = \frac{1+1.01}{288} = \frac{(P_2)_g + 1.01}{278}$

$\Rightarrow (P_2)_g = 0.93.$

$Q_v = m C_v dT$ P(absolute)

$= \frac{PV}{RT} C_v dT$

$= \frac{(1+1.01) \times 100 \times 2500 \times 10^{-6}}{0.287 \times 288} \times 0.718 (5-15).$

(39) $\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow \frac{(P_1)_g + 1.01}{288} = \frac{1+1.01}{278}$

(41) $Q_{23} = (dU)_{23} + (\delta W)_{23}$

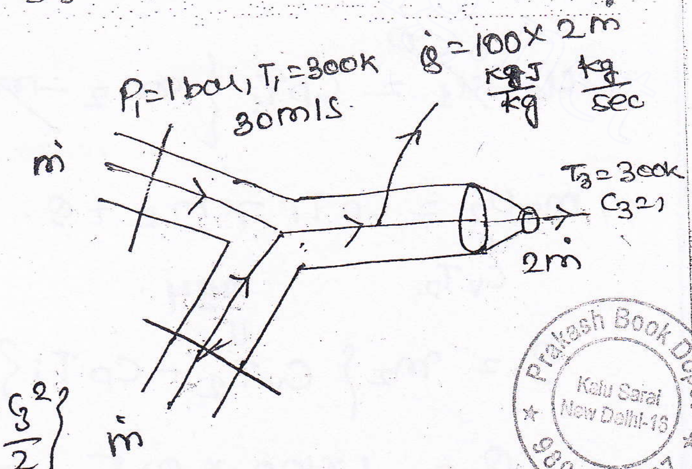
$U_3 - U_1 = 3549\ \text{kJ}$

$U_1 = U_2 \quad (\because T_1 = T_2)$

$U_3 - U_2 = 3539.$

P.K Nag

(5.17)


ṁ
$P_1 = 1$ bar, $T_1 = 300$K
30 m/s
$\dot{Q} = 100 \times 2\dot{m}$
$\frac{\text{kJ}}{\text{kg}}$ $\frac{\text{kg}}{\text{sec}}$
$T_3 = 300$K
$C_3 = ?$
2ṁ
ṁ

$\dot{m}\{\underset{\overset{\|}{C_pT_1}}{h_1} + \frac{C_1^2}{2}\} + \dot{m}\{\underset{\overset{\|}{C_pT_2}}{h_2} + \frac{C_2^2}{2}\}$

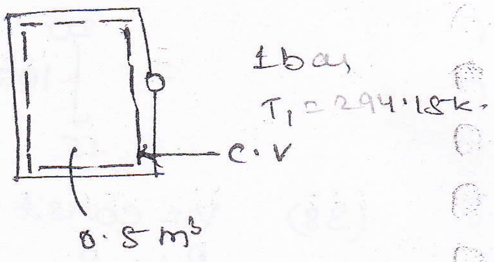
$- 100 \times 2\dot{m} = 2\dot{m}\{C_pT_3 - \frac{C_3^2}{2}\}$

$\Rightarrow \{1.005 \times 300 + \frac{(30)^2}{2} \times 10^{-3}\} + \{1.005 \times 500 + \frac{(50)^2}{2} \times 10^{-3}\}$

$- 200 = 2\{1.005 \times 300 + \frac{C_3^2}{2} \times 10^{-3}\}.$

$$\boxed{C_3 = 51.96\ m/s}$$

(5.23) No mass is exiting through C.V thus $\dot{m}_e = 0$.
Initially evacuated thus, $m_1 = 0$.
Air is an ideal gas.



$$\left(\frac{dm}{dt}\right)_{C.V} = \dot{m}_i - \cancel{\dot{m}_e}^{0} = \dot{m}_i$$

$$\left(\frac{dE}{dt}\right)_{C.V} = \dot{m}_i\left\{h_i + \frac{C_i^2}{2} + gz_i\right\} + \dot{Q} - \dot{m}_e\left\{h_e + \cancel{\frac{C_e^2}{2} + gz_e}^{0}\right\} + \cancel{W_{C.V}}^{0}$$

(1) $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\left(\frac{du}{dt}\right)_{C.V} = \left(\frac{dm}{dt}\right)h_i + \dot{Q}.$$

(2) $h_i = const$

$$\int_1^2 du = h_i\int_1^2 \frac{dm}{dt}\times dt + \int_1^2 \dot{Q}\,dt$$

$$U_2 - \cancel{U_1}^{0} = C_pT_i\left\{m_2 - \cancel{m_1}^{0}\right\}$$

$$\underset{\underset{C_vT_2}{\|}}{m_2 u_2} = C_pT_i \times m_2 + Q.$$

Final and initial temp. remains same.

$$Q = m_2\left\{C_v\overset{\overset{294}{\|}}{T_2} - C_pT_i\right\}.$$

$$Q = \frac{1\times100\times0.5}{\cancel{0.287\times294}}\times\cancel{294}\{\cancel{R}\}$$

$$\boxed{Q = -50\,KJ}$$

w_0 = P + V boundary work

Similar to Pa

$w_0 = P \cdot dV$

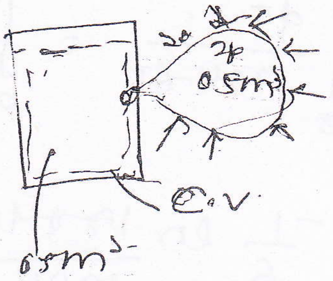
$= 1 \times 100 \times 0.5$

$= 50$ kJ.

$\delta Q = du + \delta w$

$\delta Q = 0 + (-50) = -50$ kJ.

Evacuated but not insulated.



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(5.22) Paddle wheel keeps the temp. uniform.

water is incompressible.

Thus, $u = mcT$ (only temp. is changing)

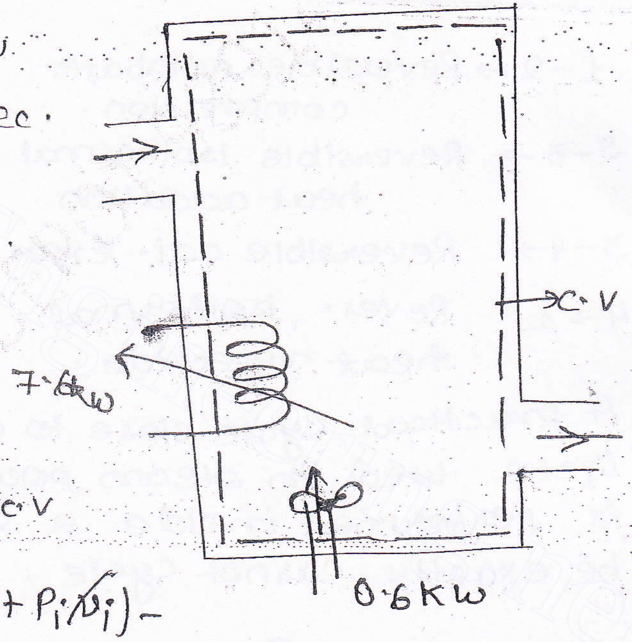
$\frac{du}{dt} = mc\frac{dT}{dt}$

$m_1 = 45$ kg.

$T_1 = 318$ K, $T_i = 318$ K,

$\dot{m}_i = \dot{m}_e = 270$ kg/sec.

$\quad\quad\quad\quad \shortparallel$
$\quad\quad\quad\quad \dot{m}$



$\left(\frac{dm}{dt}\right)_{CV} = \dot{m}_i - \dot{m}_e = 0$

$\left(\frac{du}{dt}\right)_{C.V} = \dot{m}\{h_i\} + \dot{Q} - \dot{m}\{h_e\} - \dot{w}_{c.v}$

$\Rightarrow 45 \times 4.18 \times \frac{dT}{dt} = \dot{m}\{(u_i + \cancel{P_i v_i}) - u_e + \cancel{P_e v_e})\} + \dot{Q} - \dot{w}_{c.v}$

$\Rightarrow 45 \times 4.18 \frac{dT}{dt} = 270\{4.18 \times 318 - 4.18 \times T\} + (-7.6 \times 3600) - (-0.6 \times 3600)$

$\frac{dT}{dt} = 6\{318 - T\} - 7 \times 19.138$

$\frac{dT}{dt} = 1774 - 6T$

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$$\int_{318}^{T} \frac{dT}{1774-6T} = \int_{0}^{t} dt \,.$$

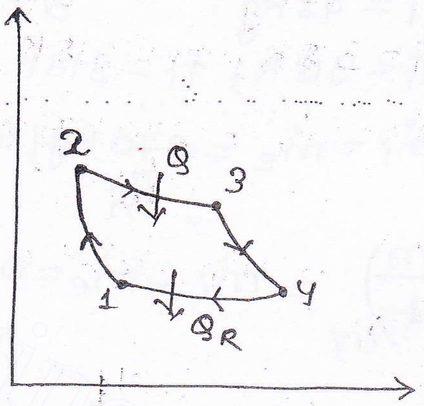
$$\Rightarrow -\frac{1}{6} \ln \frac{1774-6T}{1774-6\times318} = t \,.$$

$$\Rightarrow 1774-6T = e^{-6t} \times 134 \,.$$

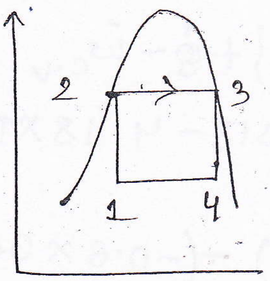
$$\Rightarrow 6T = 1774-\left(e^{-6t} \times 134\right) \Rightarrow T = 295-22e^{-6t}$$

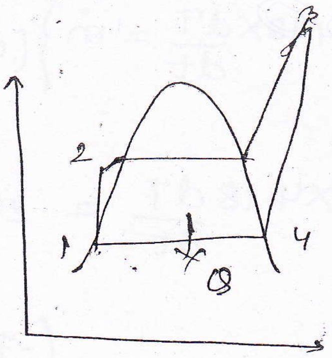
CARNOT CYCLE

1 – 2 → Reversible adiabatic compression.
2 – 3 → Reversible isothermal heat addition
3 – 4 → Reversible adi.. expa.
4 → 1 Rever. isothermal heat rejection.



A practical cycle close to carnot cycle is RANKINE CYCLE used in steam power plants if the cycle is performed inside a saturation curve it will be exactly carnot cycle.





Q-03

Nitrogen gas (Mol. wt = 28) is enclosed in a cylinder by a piston at initial condition of 2 bar, 298 K and 1 m³. In a particular process the gas slowly expands under isothermal conditions until the vol^m becomes 2 m³. The work interaction

1 bar = 100 N/m²

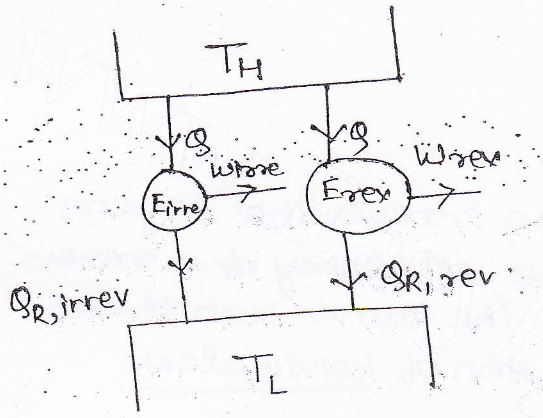
for the nitrogen gas is

sol→ $w = c \ln \frac{V_2}{V_1} = 2 \ln 2 = 1.386$
$= 138.6$ kj.

Carnot principles

(1) The efficiency of an irreversible heat engine can not exceed the efficiency of a reversible engine b/w the same two reservoirs.

(2) The efficiencies of all reversible heat engines operating b/w the same two reservoirs are same.

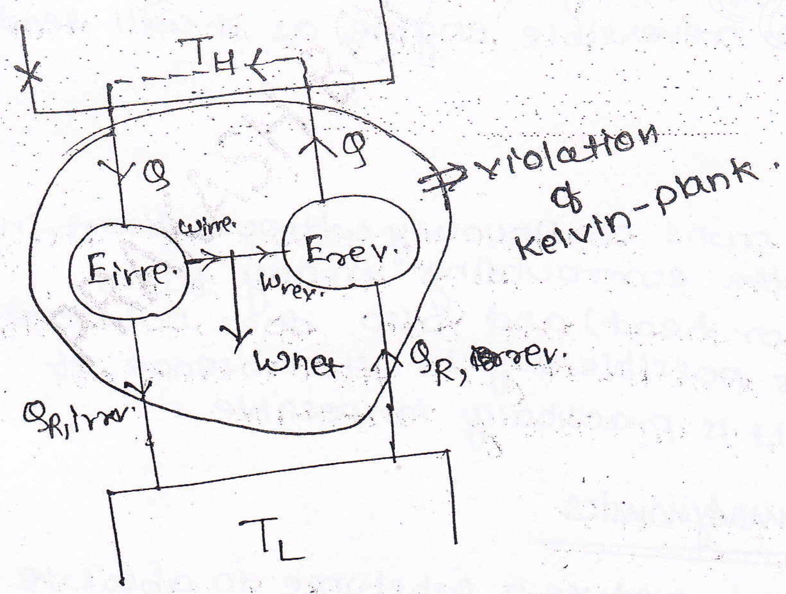


T_H
Q
Q
Eirre
Erev
Wirre
Wrev
$Q_{R,irrev}$
$Q_{R,rev}$
T_L

$$\eta_{irrev.} > \eta_{rev}$$

$$\frac{W_{irrev.}}{Q} > \frac{W_{rev}}{Q}$$

$$\boxed{W_{irrev.} > W_{rev}}$$



T_H
Q
Q
Eirre.
Erev.
wirre.
Wrev.
Wnet
$Q_{R,irrev}$
$Q_{R,rev.}$
T_L
violation of Kelvin-plank.

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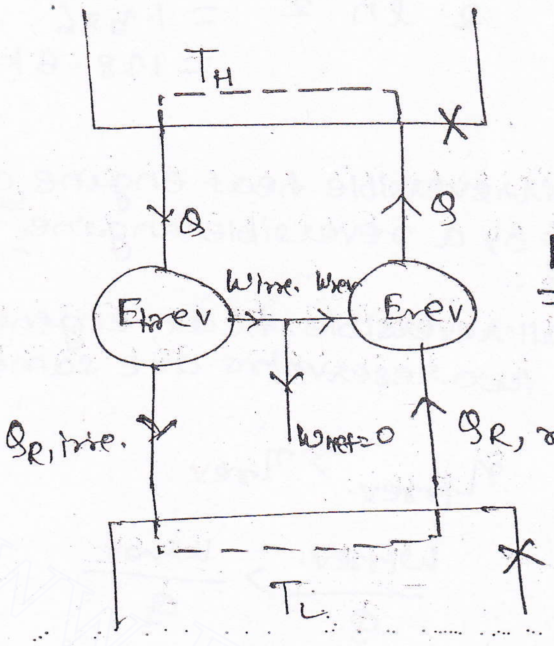
- $\eta_{rev.} = \eta_{irrev.}$



PMM – III

Hence, the efficiency of an irreversible engine can not be greater than the efficiency of a reversible engine operating b/w the same two thermal reservoirs. It is the violation of kelvin plank statement.

Moreover, the efficiency of irreversible engine can not be equal to reversible engine as it will lead to PMM III.

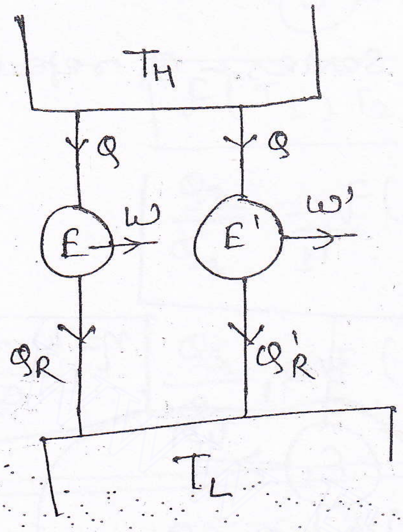
PMM III

A device which runs continuously without absorbing energy from the surrounding in any form (neither work nor heat) and also does not develop any work, it is possible only in the absence of friction. Hence, it is practically impossible.

Third law of Thermodynamics

(i) It is impossible to reduce a substance to absolute zero kelvin, no matter how idealised procedure is followed.

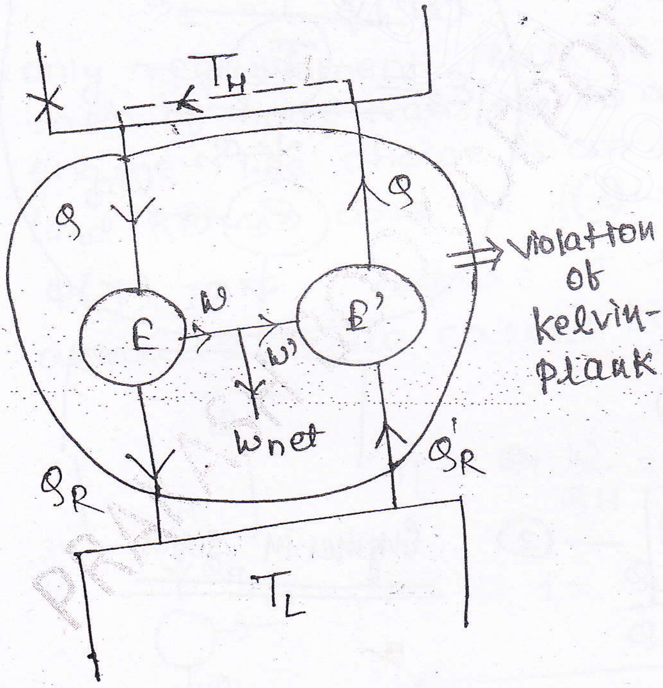
(ii) The entropy of a pure crystalline substance is zero at absolute 0K (zero temp.).

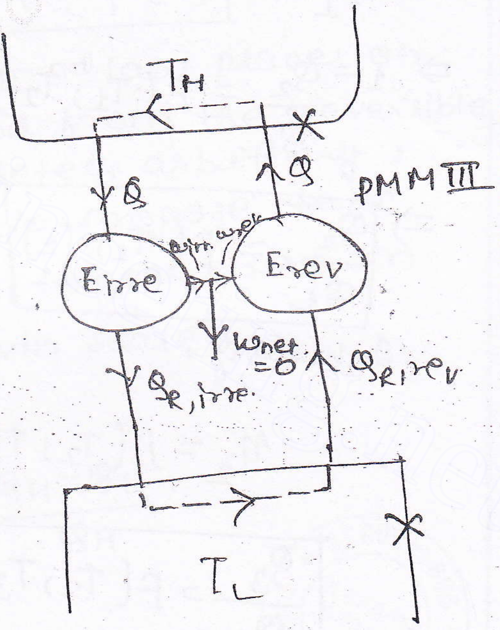

T_H
Q
Q
E
W
E'
W'
Q_R
Q'_R
T_L

$$\eta > \eta'$$

$$\frac{W}{\cancel{Q}} > \frac{W'}{\cancel{Q}}$$

$$W > W'$$


T_H
Q
Q
E
W
W'
E'
W_{net}
Q_R
Q'_R
T_L
violation of kelvin-plank


T_H
Q
Q
PMM III
E_{irre}
E_{rev}
$W_{net} = 0$
$Q_{R,irre}$
$Q_{R,rev}$
T_L

$$\eta \not> \eta' \quad \boxed{\eta = \eta'}$$

$$\eta' \not> \eta$$

Hence, the efficiency of all reversible engine working b/w same thermal reservoir is same.

Imp. points w.r.t reversible cycles

(i) Efficiency of a reversible cycle depends only on temp. limits and hence the efficiency of various reversible cycle operating b/w same temp. limits is same,

(2) Efficiency of a reversible cycle working under same temp. limits is independent of working fluid.

Thermodynamic temp. scale

when heat engines are in series - Q_1 rejected by ① absorbed by ②

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$E_1, E_2 \Rightarrow$ Reversible

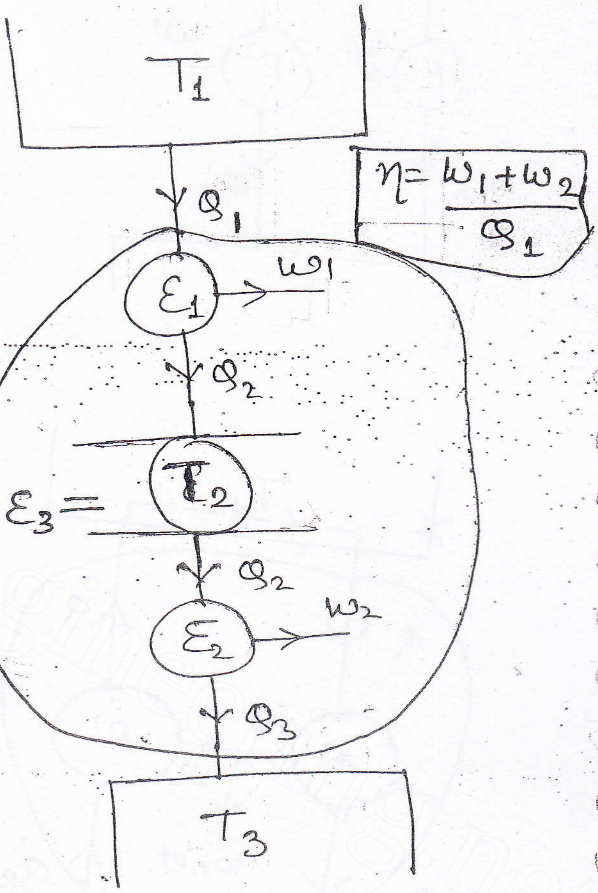
$$\eta = f(T_1, T_2)$$

$$\frac{W_1}{Q_1} = f(T_1, T_2)$$

$$\frac{Q_1 - Q_2}{Q_1} = f(T_1, T_2)$$

$$\Rightarrow 1 - \frac{Q_2}{Q_1} = f(T_1, T_2)$$

$$\Rightarrow \boxed{\frac{Q_2}{Q_1} = f(T_1, T_2)} \quad — ①$$



Engines in series

Similarly,

$$\eta_2 = f(T_2, T_3)$$

$$\boxed{\frac{Q_3}{Q_2} = f(T_2, T_3)} \quad — ②$$

① × ②

$$\boxed{\frac{Q_3}{Q_1} = f(T_1, T_2) \cdot f(T_2, T_3)} \quad — ③$$

$$\eta_3 = f(T_1, T_3)$$

$$\boxed{\frac{Q_3}{Q_1} = f(T_1, T_3)} \quad \text{—} ④$$

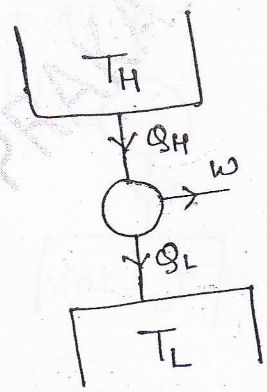
③ & ④

$$\boxed{f(T_1, T_2) = f(T_1, T_2) \cdot f(T_2, T_3)}$$

$$\frac{Q_2}{Q_1} = f(T_1, T_2) = \frac{\phi(T_2)}{\phi(T_1)}$$

$$\frac{Q_3}{Q_2} = f(T_2, T_3) = \frac{\phi(T_3)}{\phi(T_2)}$$

$\frac{Q_2}{Q_1} = \frac{\phi(T_2)}{\phi(T_1)}$, i.e, $\boxed{Q = \phi(T)}$ is the only requirement that the IInd law places on ratio of heat transfers to and from the reversible engine. The choice is completely arbitrary, Lord Kelvin was the first to propose take $\phi(T) = T$, where T is temperature in absolute scale called kelvin scale.



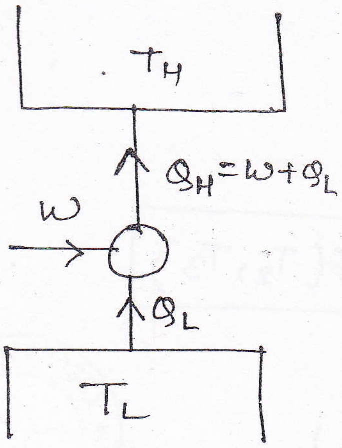
$$\eta = \cancel{Q}\frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_L}{Q_H}$$

$$\boxed{\eta_{rev} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}}$$

Heat engine

$$\eta \begin{cases} > \eta_{rev} \Rightarrow \text{Impossible.} \\ = \eta_{rev} \Rightarrow \text{Reversible.} \\ < \eta_{rev} \Rightarrow \text{Irreversible.} \end{cases}$$



$$(COP)_R = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}$$

$$= \frac{1}{\frac{Q_H}{Q_L} - 1} = \frac{T_L}{T_H - T_L}$$

$$\{(COP)_P\}_{Rev} = \frac{T_L}{T_H - T_L}$$

$$\boxed{(COP)_{Prefrigerator} = \frac{T_L}{T_H - T_L}}$$

$$\boxed{\left\{(COP)_{Heat\ pump}\right\}_{Rev} = \frac{T_H}{T_H - T_L}}$$

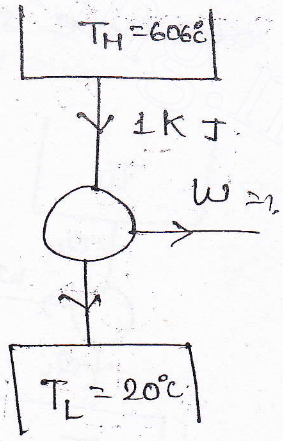
⑧ In a reversible heat engine operating in a cycle between a source and and sink temp. of 606°c and 20°c resp. what will be the work done per KJ of heat supplied to the engine.

Sol→ $T_H = 606°c$, $T_L = 20°c$.

~~ω=~~ $\eta = 1 - \frac{T_L}{T_H}$

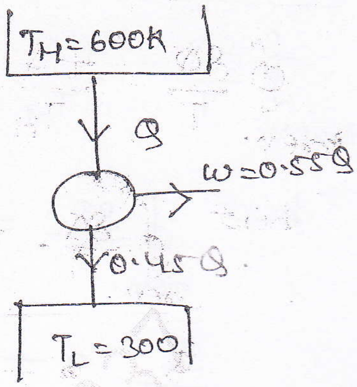
$\Rightarrow \frac{W}{q_H} = 1 - \frac{293}{879}$

$\Rightarrow W = 0.666$ KJ.



⑧ A inventor claims that his new concept of an engine while working b/w the temp. limits of 27°c and 327°c rejects 45% of the heat absorbed from the source.

His engine then equivalent to which one of the following engines
(i) Otto (ii) Carnot (iii) Impossible.



Sol $T_H = 600K$, $T_L = 300K$.

$Q_L = 0.45Q$.

$$\eta_{actual} = \frac{W}{Q}$$

$$= \frac{0.055Q}{Q} = 0.55$$

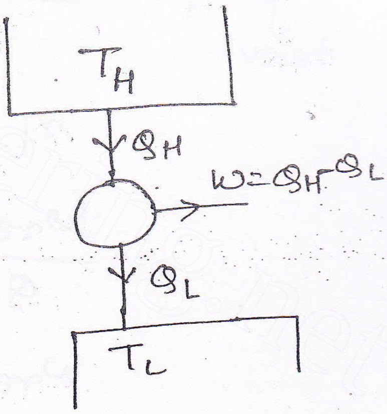
$$\eta_{rev} = 1 - \frac{T_L}{T_H}$$

$$= 1 - \frac{300}{600} = 0.5$$

$\eta_{actual} > \eta_{rev}$, therefore this is impossible.

Clausius Inequality

$$\boxed{\oint \frac{\delta Q}{T} \leq 0}$$



$$\oint_{rev} \frac{\delta Q}{T} = +\frac{Q_H}{T_H} - \frac{Q_L}{T_L}$$

but if rev.

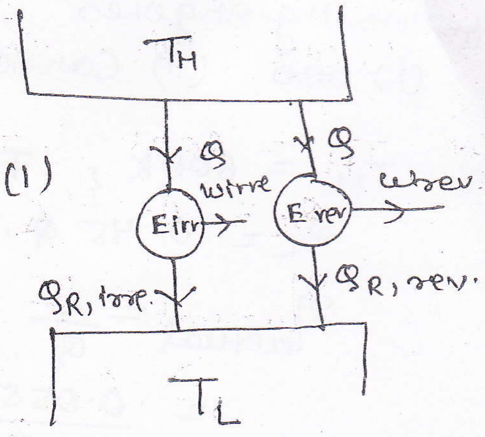
$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

$$\frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

$$\boxed{\oint_{rev} \frac{\delta Q}{T} = 0}$$

Case II

Irreversible


T_H
Q
Q
W_{irre}
W_{rev}
Eirr
E rev
$Q_{R,irr}$
$Q_{R,rev}$
T_L

$$\oint_{irrev} \frac{\delta Q}{T} = \frac{+Q}{T_H} - \frac{Q_{R,irrev}}{T_L} \quad \text{—— (1)}$$

but $\oint_{rev} \frac{\delta Q}{T} = 0$

$$\frac{Q}{T_H} - \frac{Q_{R,rev}}{T_L} = 0$$

$$\boxed{\frac{Q}{T_H} = \frac{Q_{R,rev}}{T_L}} \quad \text{—— (II)}$$

Putting (II) in (1), we get

$$\oint_{irrev} \frac{\delta Q}{T} = \frac{Q_{R,rev}}{T_L} - \frac{Q_{R,irrev}}{T_L}$$

$$\eta_{rev} > \eta_{irre}.$$

$$\frac{W_{rev.}}{Q} > \frac{W_{irrev.}}{Q}$$

$$W_{rev.} > W_{irrev}.$$

$$Q - Q_{R,rev.} > Q - Q_{R,irrev}.$$

$$Q_{R,rev} < Q_{R,irrev}.$$

$$\boxed{\oint_{irrev} \frac{\delta Q}{T} < 0}$$

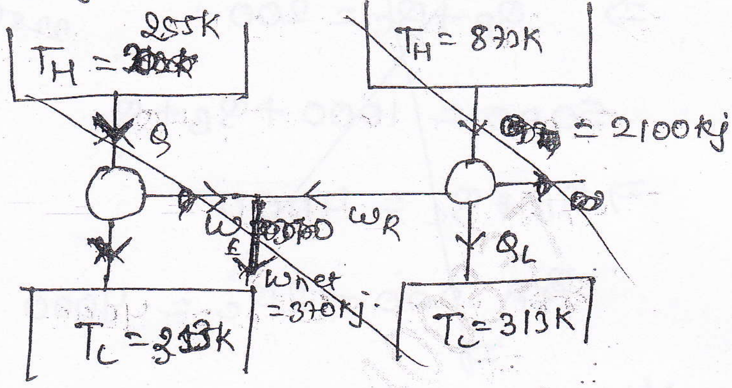
(Q) A reversible heat engine operates b/w 600°C & 40°c. This engine drives a reversible refrigerator operating b/w 40°c & −18°c. Still there is a net work output of 370 kj, while the heat received by the engine is 2100 kj. Determine the cooling effect of the refrigerator?

Sol, $T_H = 873K$

$W_{net} = 370 kj$

~~$Q_H = W + Q_L$~~

~~$(Q_L)_R + W_R = (Q_H)_R$~~


$T_H = 255K$
Q
W_E
W_R
Wnet = 370kj
$T_C = 313K$
$T_H = 873K$
$Q = 2100kj$
Q_L
$T_C = 313K$

⇒ ~~$2100 = W + Q_L$~~

~~2100 + 370~~

$$(COP)_R = \frac{Q}{W_R} \Rightarrow \frac{255}{313-255} = \frac{Q}{W_R}$$

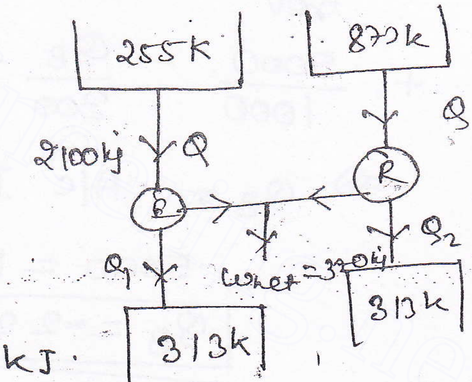
$$\Rightarrow W_R = W_E - W_{net}$$

$$\eta_E = \frac{W_E}{2100}$$

$$1 - \frac{313}{873} = \frac{W_E}{2100}$$

$$W_E = 1347.079 kJ.$$

$$\Rightarrow Q = 4295 kJ.$$


255K
873K
2100kj
Q
Q
E
R
Q_1
Q_2
Wnet = 370kj
313k
313k

Total heat rejected to reservoir ~~[illegible]~~.
$= Q_1 + Q_2$.

(Q) Diagram below shows a device exchanging ~~A~~ heat with three thermal energy reservoirs. It works on a reversible cycle and develops 1000 kj of work. Find the magnitude and directions of Q_B & Q_c.

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~~$\frac{Q}{W} = 1 - \frac{800}{1000}$~~

~~$\Rightarrow$ 500 $\frac{Q_B+Q_C}{1000} = \frac{200}{1000}$~~

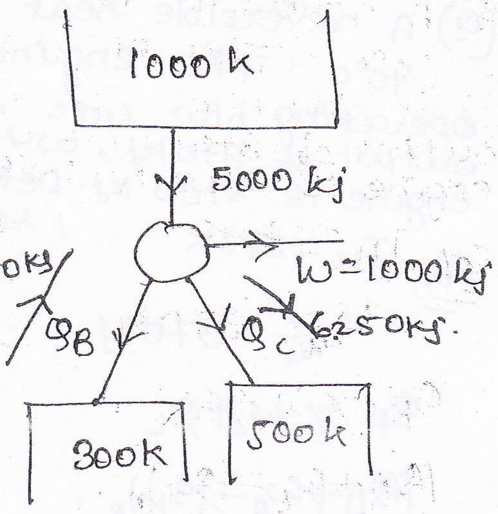
~~$\Rightarrow Q_B + Q_C = 200$.~~

~~$5000 = 1000 + Q_B + Q_C$~~

~~$\Rightarrow Q_B - Q_C = 4000$.~~

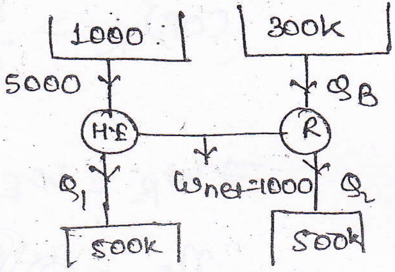
~~Q_B $200 - 2Q_C = 4000$~~

~~$\Rightarrow$~~


1000 k
5000 kj
W = 1000 kj
2250 kj
Q_B
Q_C
6250 kj.
300k
500 k

Let Q_B and Q_C both are going out of the Engine towards the reservoir.

$$\oint_{rev} \frac{\delta Q}{T} = 0.$$


1000
300k
5000
Q_B
H.E
R
Q_1
$W_{net} = 1000$
Q_2
500k
500k

$$+\frac{5000}{1000} - \frac{Q_B}{300} - \frac{Q_C}{500} = 0$$

$\Rightarrow Q_B =$ A/c Ist law of Thermodynamics

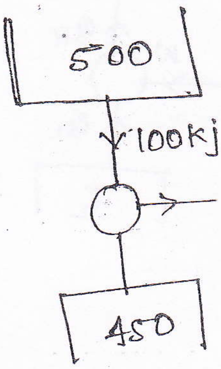
$$5000 = 1000 + Q_B + Q_C.$$

$$\boxed{Q_B = -2250 \text{ kj}}.$$

$$\boxed{Q_C = 6250 \text{ kj}}$$

Note

If a device is shown exchanging heat with more than 2-reservoirs than use of clausius inequality is beneficial if we want to use 2nd law of thermodynamics.



$$\eta = \frac{9.5}{100} = 0.095$$

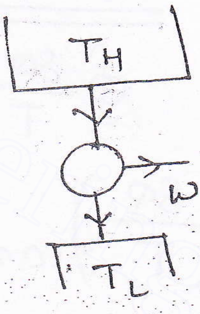
$$\eta = 9.5\%$$

$$\eta_{rev} = 1 - \frac{450}{500} = 0.1 = 10\%$$

$$\eta_{II} = \frac{\eta_a}{\eta_{rev}} \quad , \quad \eta_{II} = \frac{9.5}{10} = 0.95 = 95\%$$

$$\eta_{II} = \frac{(COP)_a}{(COP)_{Rev}}$$

Effect of source and sink temp. on the efficiency of a reversible engine



$$\eta_{rev} = 1 - \frac{T_L}{T_H} = \frac{T_H - T_L}{T_H}$$

(i) $T_L \downarrow$ by ΔT

$$\eta_{rev} = \frac{T_H - (T - \Delta T)}{T_H}$$

$$\boxed{\eta_{rev} = \frac{T_H - T_L + \Delta T}{T_H}}$$

(2) $T_H \uparrow$ by ΔT

$$\eta_{rev} = \frac{(T_H + \Delta T) - T_L}{T_H + \Delta T}$$

$$= \frac{(T_H - T_L) + \Delta T}{T_H + \Delta T} \rightarrow \overset{T_H}{\text{increase}}\ \eta.$$

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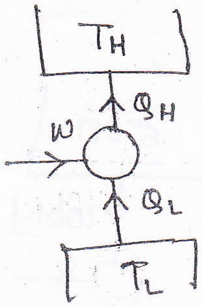
$$(COP)_{HP} = \frac{T_H}{T_H - T_L}$$



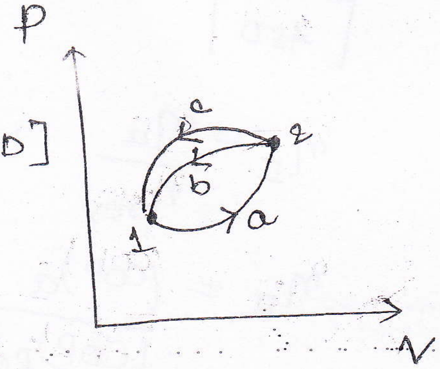
$T_L \uparrow$ is more beneficial.

- Reversible → Dashed line.

Irreversible → Dotted line.

Entropy

1 – a – 2 – b – 1



$$\oint_{rev} \frac{\delta Q}{T} = 0 \quad [\text{clausius } \text{II law of T.D}]$$

$$\left(\frac{\delta Q}{T}\right)_{1a2} + \left(\frac{\delta Q}{T}\right)_{2b1} = 0$$

1 – a – 2 – c – 1

$$\oint \frac{\delta Q}{T} = 0.$$

$$\left(\frac{\delta Q}{T}\right)_{1a2} + \left(\frac{\delta Q}{T}\right)_{2c1} = 0 \quad \text{— ②}$$

① – ②

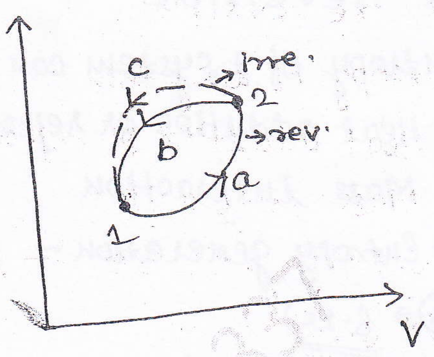
$$\left(\frac{\delta Q}{T}\right)_{2b1} - \left(\frac{\delta Q}{T}\right)_{2c1} = 0$$

$$\Rightarrow \left(\frac{\delta Q}{T}\right)_{2b1} = \left(\frac{\delta Q}{T}\right)_{2c1}$$

$$\boxed{\left(\frac{\delta Q}{T}\right)_{rever.} = ds}$$ (point f^n a property)

Though path 'b' and 'c' are different but the end pts are same and the quantity $\left(\frac{\delta Q}{T}\right)_{rev}$.

Is independent of the path and depends only on the initial and final points and hence It must represent a change in property and that property is called **Entropy**.



1-a-2-b-1

$$\oint_{rev}\left(\frac{\delta Q}{T}\right)=0$$

$$\left(\frac{\delta Q}{T}\right)_{1a2}+\left(\frac{\delta Q}{T}\right)_{2b1}=0$$

$$\left(\frac{\delta Q}{T}\right)_{1a2}=-\cancel{\oint}\left(\frac{\delta Q}{T}\right)_{2b1}$$

1-a-2-c-1

$$\oint_{irre.}\left(\frac{\delta Q}{T}\right)<0$$

$$\left(\frac{\delta Q}{T}\right)_{1a2}+\left(\frac{\delta Q}{T}\right)_{2c1}<0$$

$$\left(\frac{\delta Q}{T}\right)_{2c1}<-\left(\frac{\delta Q}{T}\right)_{2a2}$$

$$\left(\frac{\delta Q}{T}\right)_{2c1}<\left(\frac{\delta Q}{T}\right)_{2b1}$$

$$\left(\frac{\delta Q}{T}\right)_{irre.}<\left(\frac{\delta Q}{T}\right)_{rev.}$$

$$\boxed{\left(\frac{\delta Q}{T}\right)_{irrer.}<ds}$$

$$\boxed{ds\geq\frac{\delta Q}{T}}$$

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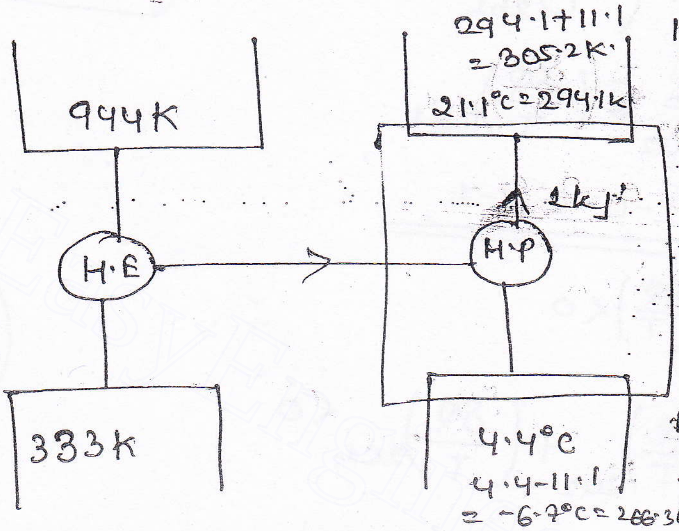
Hence, the entropy change between an initial and final state is always greater than or equal to $\left(\frac{\delta Q}{T}\right)$ evaluated for a process between the end points. The equality holds if the process is reversible.

Entropy of a system can change in following three ways:-

(i) Heat addition or rejection
(ii) Mass interaction
} External interaction
(iii) Entropy generation → Internal irreversibility.

NAG Ⓠ → 6.11)



Here temp must be more the working fluid for effective heat transfer.

Here temp must be less than the working fluid.

working fluid temp as source or sink when nothing is given.

50% of carnot engine.

$$COP = \frac{1}{2}\left(\frac{T_H}{T_H - T_L}\right) = \frac{1}{W}$$

$$\Rightarrow COP = \frac{1}{2}\left[\frac{305.2}{305.2 - 266.3}\right] = \frac{1}{W}$$

$$\Rightarrow W = \text{[illegible]}\ 0.2549\ kJ.$$

$$\eta_{engine} = \frac{1}{2}\left(1 - \frac{333}{944}\right) = \frac{W}{Q}$$

$$\Rightarrow Q = 0.79\ kJ.$$

(6.13), (6.21)

① ⓓ ② ⓐ ③ ④ ⑤ c ⑥ a ⑦ a ⑧ c

⑨ ⑩ c ⑪ d ⑫ c ⑬ b ⑭ d ⑮ a ⑯ d

⑰ d ⑱ ⑲ ⑳ ⓐ

(10) $du + \delta w = 0 \Rightarrow du = -\delta w$

(11)

	Q	ΔW	ΔU
1−2 →	+50	0	+50
2−3 →	+500	~~+~~ −500	0
3−1 →		−200	−50

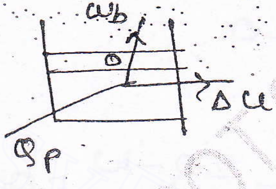
change in internal energy for cycle = 0.

(12) Burst baloon – free expansion takes place.

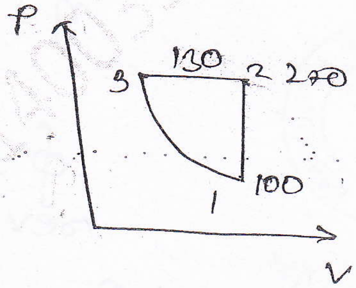
~~(18)~~ (17) $\gamma = \frac{7}{5} = 1.4$ (diatomic)

Ideal gas

$$\frac{\Delta u}{Q_p} = \frac{mC_v dT}{mC_p dT}$$



(15)



Heat supplied at const. pres. = $mC_p dT$.

Total Energy supplied = $mC_p dT$.

Fraction is always = $mC_v dT$

$$\therefore \frac{\Delta u}{Q_p} = \frac{1}{\gamma} = \frac{5}{7}.$$

How much % heat absorbed by gas depends on γ.

$\frac{1}{1.67} \times 100$ (% of energy stored as internal energy)

$= 59.88 \simeq 60\%$.

$\therefore$ 40% → work

⑨ which of the following gases will do the maxm work if the same heat is supplied at constant pressure.

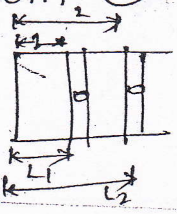
✓ (a) Monoatomic (b) Diatomic (c) Triatomic (d) Same.

⑨ work transfer in an adiabatic process is in

(a) path f^n (b) Pt. f^n

(c) property (d) Both ⓑ & ⓒ.

(19) $V = A \times L$ $\left(\frac{T_1 V_1}{\cancel{a}}\right)^{\gamma-1} = T_2 V_2^{\gamma-1}$



Suddenly → Non quasistatic

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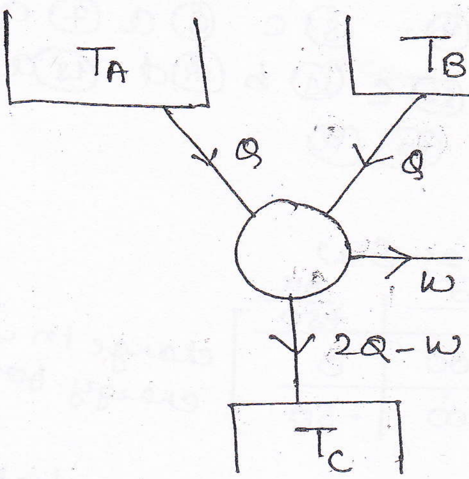
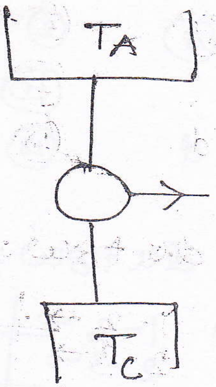
(6.13)





$$\eta = \frac{W}{2Q} = \alpha\left(1 - \frac{T_C}{T_A}\right)$$

$$\oint_{rev} \frac{\delta Q}{T} = 0$$

$$+\frac{Q}{T_A} + \frac{Q}{T_B} - \frac{2Q - W}{T_C} = 0$$

$$\frac{\cancel{Q}1}{T_A} + \frac{1}{T_B} - \frac{2 - \frac{W}{Q}}{T_C} = 0$$

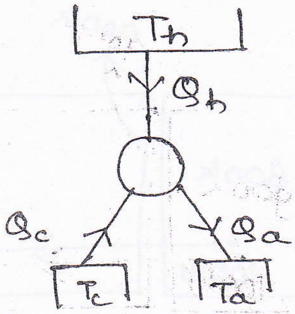
$$\Rightarrow \left(\frac{1}{T_A} + \frac{1}{T_B}\right)T_C = 2 - \frac{W}{Q}$$

$$\Rightarrow \frac{W}{Q} = 2 - \left(\frac{1}{T_A} + \frac{1}{T_B}\right)T_C$$

$$\therefore \quad 1 - \left(\frac{1}{T_A} + \frac{1}{T_B}\right)2T_C = \alpha\left(1 - \frac{T_C}{T_A}\right)$$

$$\Rightarrow \quad T_A - \left(1 + \frac{T_A}{T_B}\right)2T_C = \alpha\,(T_A - T_C)$$

(6·21) $Q_h + Q_c = Q_a$



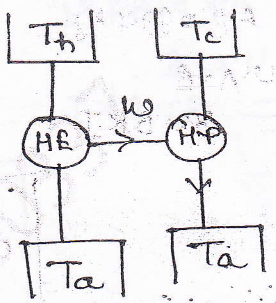
T_h
Q_h
Q_c
Q_a
T_c
T_a

$$\oint_{rev} \frac{\delta Q}{T} = 0$$

$$\Rightarrow Q_c + Q_h$$

$$+\frac{Q_h}{T_h} + \frac{Q_c}{T_c} - \frac{Q_a}{T_a} = 0$$

Reversible →
Input minimum.
Output Maximum.



T_h
T_c
W
HE
HP
T_a
T_a

$$\frac{Q_h}{Q_c}\left(\frac{1}{T_h}\right) + \frac{1}{T_c} - \frac{1}{T_a}\left(1 + \frac{Q_h}{Q_c}\right) = 0.$$

$$\frac{Q_h}{Q_c} = \frac{T_a - T_c}{T_c} \times \frac{T_h}{T_h - T_a} = 2.$$

If $Q_c = 12\,KW$

$Q_h = 24\,KW$.

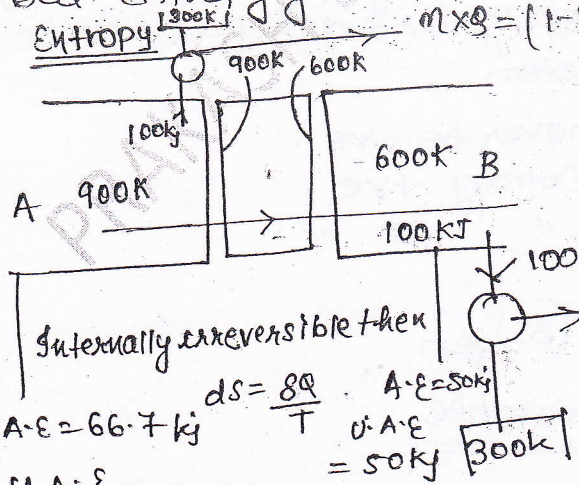
$A = 120\,m^2$.

17/11/13

Entropy is a property
but Entropy generation is not a property.

Entropy

$\eta \times Q = \left(1 - \frac{300}{900}\right)100 = 66.7$



300K
900K
600K
100kj
600K
B
A
900K
100KJ
Internally irreversible then

$100\,kj$

$100 \times \left(1 - \frac{300}{600}\right)$

$= 50\,kj$

$ds = \frac{\delta Q}{T}$

$A \cdot E = 66.7\,kj$

$A \cdot E = 50\,kj$

$U \cdot A \cdot E = 50\,kj$

300k

$U \cdot A \cdot E = 33.3\,KJ.$

$$\boxed{ds = \frac{\delta Q}{T_A}}$$

$$\boxed{\frac{\delta Q}{T_B} = ds}$$

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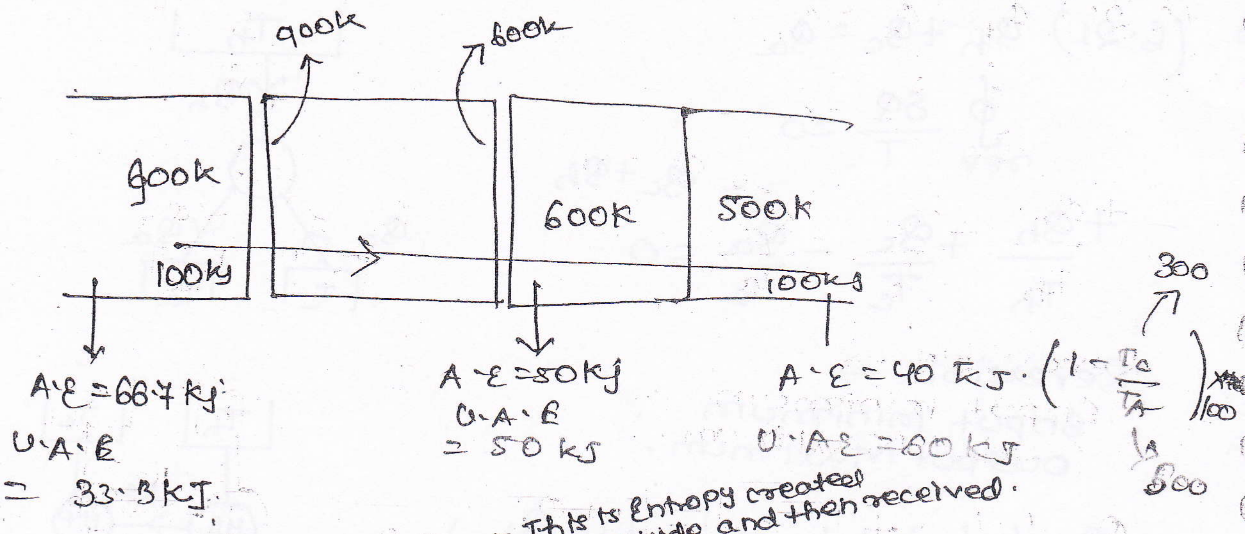
900k
600k
900k
100kJ
600K
500K
100kJ
A·E = 66.7 kJ
U·A·E = 33.3 kJ
A·E = 50 kJ
U·A·E = 50 kJ
A·E = 40 kJ · $\left(1 - \frac{T_c}{T_A}\right) \times 100$
U·A·E = 60 kJ
300
800

This is Entropy created outside and then received.

$$\boxed{ds = \frac{\delta Q}{T} + (\delta S)_{generated}}$$

This Entropy is generated internally by the system itself.

$$\boxed{\begin{array}{l} ds = \left(\frac{\delta Q}{T}\right)_{\text{internally reversible}} \\ ds > \left(\frac{\delta Q}{T}\right)_{\text{int·irrev.}} \end{array}}$$

Though Entropy is a property but the Entropy generation is not a property and depends on the path followed by the system.

- Entropy generation can never be −ve.
- Internally reversible Entropy +ve.
- " irreversible " 0.

$$ds = \frac{\delta Q}{T} + (\delta s)_{gen}$$

If internally reversible

$$ds = \frac{\delta Q}{T}$$

$$\oint ds = \oint \frac{\delta Q}{T}.$$

$$0 = \oint \frac{\delta Q}{T}$$

For internally irreversible

$$dS = \frac{\delta Q}{T} + (\delta S)_{gen}$$

$$\oint dS = \oint \frac{\delta Q}{T} + \oint (\delta S)_{gen}$$

$$0 = \oint \frac{\delta Q}{T} + (+ve)$$

$$\oint \frac{\delta Q}{T} = (-ve)$$ [Entropy received < Entropy ~~taken~~ sent out]

$$\boxed{\oint \frac{\delta Q}{T} < 0}$$

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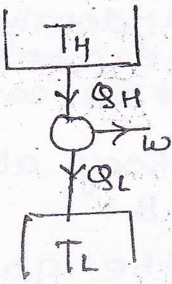
Reversible / Internally reversible

$$+\frac{Q_H}{T_H} = +\frac{Q_L}{T_L}$$



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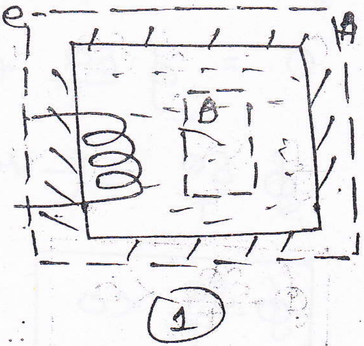
$$\Rightarrow \boxed{\frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0}$$

All ~~cyc~~ processes of 2nd law are internally reversible.

- All the relations which we have derived ~~box~~ in 2nd law for reversible process or cycle are valid for internally reversible process or cycle.
- A process is called as internally reversible if no entropy is generated inside the system.
- A process is called externally reversible if no entropy generation takes place outside the system.
- A process is called reversible process if no entropy generation takes place anywhere (i.e, inside the system or outside) due to the process.

- That is a process is reversible only when it is both internally and externally reversible.
- The entropy generation can never be −ve.
  - work → Available energy.

①
- Taking container and its contents → Energy crosses A in form of work
- Energy kept at some temp – it contains both available and unavailable enegy.
- No available enegy crossing boundary A.

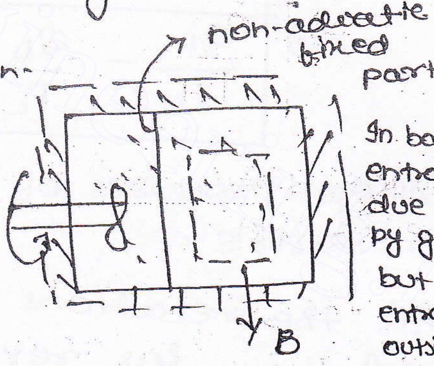


①

- When electricity is supplied molecules randomly vibrate and heat eneigy generated & crosses boundary ~~B~~ in form of Heat enegy.
  - Advection + conduction → convection

Entropy also crosses boundary ~~A~~ B.

- If the gas inside the container system is taken as the system then the system is constant vol- Energy enters the system as heat when gas is taken as system as pressure↑ & Temp↑.



In both case, entropy↑ due to entropy generation but not the entropy from outside.

②

- If the container along with contents taken as system enegy is in form of work.

②
- crossing A in form of work.
- Radom motion of gases ~~hit~~ increase the temp molecules in other parts thus the enegy is in form of heat.
- Enegy in form of work can not transfer entopy.

- Energy in form of K.E is totally available energy.
- If a ball is hit in a room, the entropy increases due to mass transfer.

Imp

- since work, K.E, Potential energy are totally available energies and hence no entropy is associated with these energies ~~as work~~

Entropy analysis for the closed system

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$$\boxed{ds = \frac{\delta Q}{T} + (\delta S)_{gen}}$$

Case1 : Internally reversible $(\delta S = 0)$

$$\boxed{ds = \frac{\delta Q}{T}}$$

(i) Heat is added to the system $(\delta Q \Rightarrow +ve)$

$$\boxed{ds = \frac{\delta Q}{T}} \Rightarrow +ve \text{ (Increases)}$$

(ii) Heat is rejected

$$\boxed{ds = \frac{\delta Q}{T}} \Rightarrow -ve \text{ (Decreases)}$$

(iii) Adiabatic $(\delta Q = 0)$ [Entropy = const.]

$$\boxed{ds = 0} \text{ [Isentropic]}.$$

Case B :- Internally irreversible

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(i) Heat added $(\delta Q = +ve)$

$$\boxed{ds = \underbrace{\frac{\delta Q}{T}}_{+ve} + \underbrace{(\delta S)_{gen}}_{+ve}} \Rightarrow +ve \text{ (increases)}.$$

(ii) Adiabatic ($\delta Q = 0$)

$$ds = \cancelto{0}{\frac{\delta Q}{T}} + \underbrace{(\delta s)_{gen}}_{(+ve)} \Rightarrow +ve$$

$$\boxed{ds = (\delta s)_{gen}} \text{ (increases)}$$

(iii) Heat rejection ($\delta Q = -ve$)

$$\boxed{ds = \underbrace{\frac{\delta Q}{T}}_{-ve} + \underbrace{(\delta s)_{gen}}_{+ve}} \Rightarrow +ve, -ve, 0 \text{ [Isentropic]}$$

Entropy can not remain conserved but can be constant.

Entropy change of the universe

universe is an isolated system.

∵ the system is isolated thus no heat transfer takes place ($\delta Q = 0$)

$$(ds)_{uni.} = \cancelto{0}{\frac{\delta Q}{T}} + (\delta s)_{gener.}$$

$$\boxed{(ds)_{uni.} = (\delta s)_{gene}}$$

$(\delta s)_{gen.}$ is always +ve.

Thus,

$$\boxed{(ds)_{univ.} \geq 0}$$

The amount by which entropy generated increases the entropy of universe by same amount.

- The entropy of the system can increased, decreased or remains const. but the entropy of isolated system can never decreased.
- Since universe is an isolated system its entropy can never decrease. The entropy of the universe changes only due to entropy generation. Hence, the entropy of the universe remains const. for a reversible process but keeps on increasing for real processes.

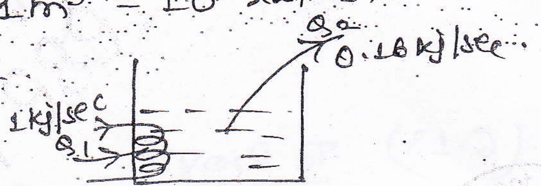
This is known as Increase of Entropy principle.

Hence, entropy is not a conserved property.

(W.B) Page-16

(23) $\rho_w = 1000\ kg/m^3$, $1 m^3 = 10^3$ litres,

$1000 kg/m^3 \Rightarrow 1 kg/ltr.$



Close system as no mass transfer takes place.

$$\delta Q = du + \delta W$$

$$\delta Q = du + \cancelto{0}{\delta W_b} + \cancelto{0}{\delta W_0}$$

Energy is absorbed by water in form of heat.

$$Q_{net} = Q_1 - Q_2$$

$$(1 - 0.16) \times t = mCT$$

$$\Rightarrow (1 - 0.16)t = m \times C \times (77 - 27)$$

$$\Rightarrow (1 - 0.16)t = 2 \times 4.2 \times (50)$$

$$t = 500 sec.$$

$t = 8.33$ ~~sec~~ min.

$= 8$ min $(.33 \times 60)$ sec.

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(24) Const. temp. → means sensible part of energy remains same ∴ some chemical energy get converted into thermal energy.

$u_1 \to u_2$

$$\delta Q = du + \cancel{\delta w}^{\,0}$$

Kcal = 4.18 kJ

$$du = -250 \times 4.18$$

Again, charging takes place.

$u_2 \to u_1$

$$\delta Q = du + \cancel{\delta W_b}^{\,0} + \delta W_0$$

$$\delta Q = (-250 \times 4.18) + (0.53 \times 3600)$$

KWH

1KW → 1Hr.

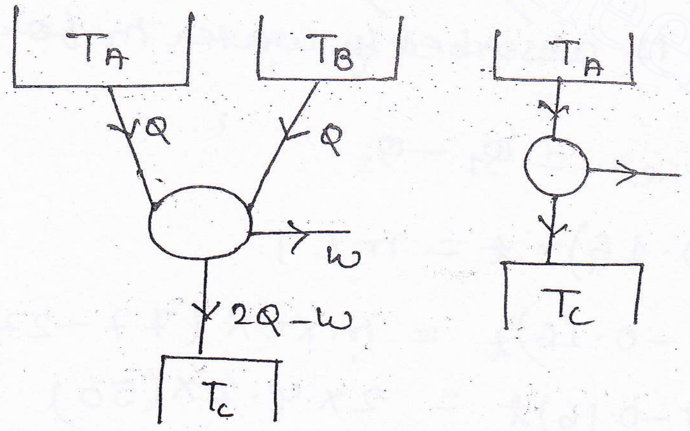
1kJ/sec × 3600sec.

Energy consumed

3600kJ = 1kWH

(6.13) To Prove

$$\frac{T_A}{T_B} = (2\alpha - 1) + 2(1-\alpha)\frac{T_A}{T_C}$$



Given

$$\eta = \frac{W}{2Q} = \alpha\left(1 - \frac{T_C}{T_A}\right) \quad \text{——} \quad (1)$$

$$\oint_{rev.} \frac{\delta Q}{T} = 0$$

$$\frac{Q}{T_A}+\frac{Q}{T_B}=\frac{2Q-W}{T_C}$$

$$\Rightarrow \frac{T_C}{T_A}+\frac{T_C}{T_B}=\left(2-\frac{W}{Q}\right)$$

$$\Rightarrow \frac{W}{Q}=2-\left(\frac{T_C}{T_A}+\frac{T_C}{T_B}\right)$$ [Putting this value in ①]

$$2-\left(\frac{T_C}{T_A}+\frac{T_C}{T_B}\right)=2\alpha\left(1-\frac{T_C}{T_A}\right)$$

$$\Rightarrow 2-\frac{T_C}{T_A}\cancel{+}-\frac{T_C}{T_B}=2\alpha-2\alpha\frac{T_C}{T_A}$$

$$\Rightarrow 2-\frac{T_C}{T_B}=2\alpha-2\alpha\frac{T_C}{T_A}+\frac{T_C}{T_A}$$

$$\Rightarrow 2-\frac{T_C}{T_B}=2\alpha+(1-2\alpha)\frac{T_C}{T_A}$$

Multiplying both the sides by $\frac{T_A}{T_C}$, we get

$$\frac{2T_A}{T_C}-\frac{T_A}{T_B}=2\alpha\cdot\frac{T_A}{T_C}+(1-2\alpha)$$

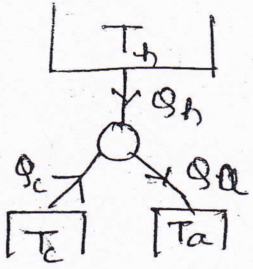
$$\Rightarrow \frac{T_A}{T_B}=2\frac{T_A}{T_C}-2\alpha\cdot\frac{T_A}{T_C}+(-1+2\alpha)$$

$$\Rightarrow \boxed{\frac{T_A}{T_B}=2(1-\alpha)\frac{T_A}{T_C}+(2\alpha-1)}$$

(6.21) $Q_h=Q_c+Q_a$

$$\oint\frac{\delta Q}{T}=0$$

$$\frac{Q_h}{T_h}+\frac{Q_c}{T_c}-\frac{Q_a}{T_a}=0$$



$$\frac{Q_h}{Q_c}\left(\frac{1}{T_h}\right) + \frac{1}{T_c} - \frac{1}{T_a}\left(1 + \frac{Q_h}{Q_c}\right) = 0$$

$$\Rightarrow \frac{Q_h}{Q_c} = \frac{\frac{1}{T_a}\left(1 + \frac{Q_h}{Q_c}\right) - \frac{1}{T_c}}{1/T_h}$$

$$\Rightarrow \frac{Q_h}{Q_c} = \frac{\frac{1}{300}\left(1 + \frac{Q_h}{Q_c}\right) - \frac{1}{200}}{1/400}$$

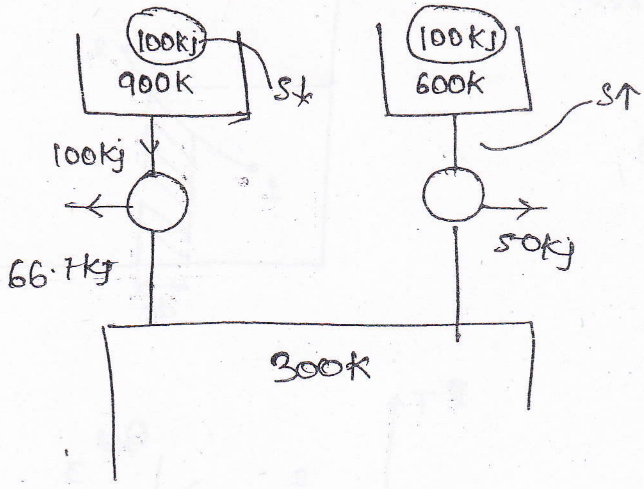
$$\Rightarrow \frac{Q_h}{400Q_c} = \frac{1}{300} + \frac{Q_h}{300Q_c} - \frac{1}{200}$$

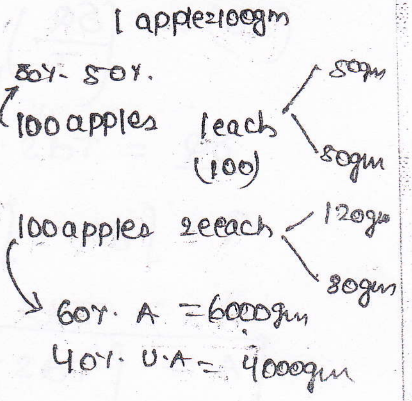
$$\Rightarrow \left(\frac{1}{400} - \frac{1}{300}\right)\frac{Q_h}{Q_c} = \frac{1}{300} - \frac{1}{200}$$

$\Rightarrow \frac{Q_h}{Q_c} =$ ~~-2.99~~ 2

$\therefore Q_h = 2Q_c = 2 \times 12 = 24\,\text{kW}$

18|11|13


100kJ
900K
S↓
100kJ
66.7kJ
100kJ
600K
S↑
50kJ
300K


1 apple=100gm
50%- 50%
100 apples
1each
(100)
50gm
50gm
100 apples
2each
120gm
80gm
60% A = 6000gm
40% U.A = 4000gm

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Entropy is a function of temp. and vol.

(a) Volume

Higher the volume, Higher will be the entropy and vice-versa.

(b) Temperature

The total entropy associated with the total energy is lower at higher temp. and higher at lower temp.
whereas the entropy per unit molecule is lower at lower temp. and higher at higher temp.

Entropy can be viewed as a measure of molecular disorderness or randomness, as the system becomes more and more disorder the position of the molecules become less predictable and hence entropy increases.

Entropy of a substance is lowest in solid phase & highest in gaseous phase.

Temperature entropy diagram (T-S DIAGRAM)

Area under TS diagram has no meaning for internally irreversible (Eg:- Throttling).

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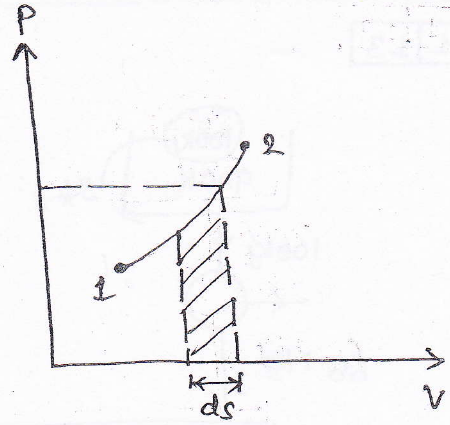
$$(ds) = \left(\frac{\delta Q}{T}\right)_{int.\ rev.}$$

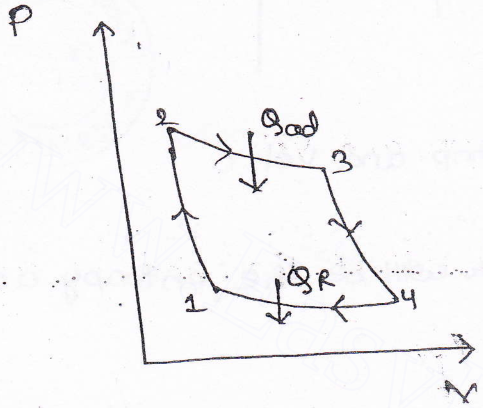
$$\underline{\delta Q} = Tds$$

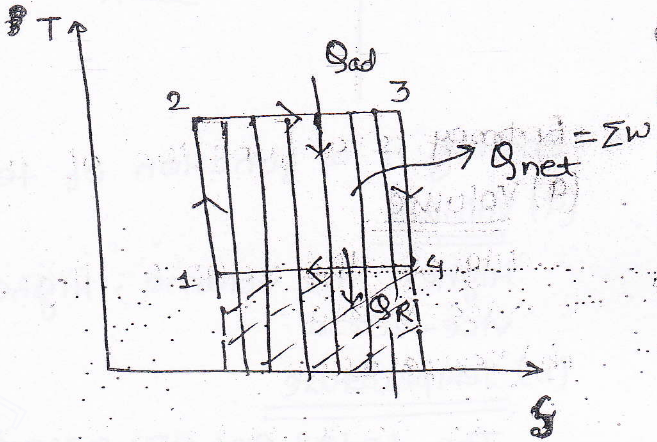
$$Q = \int \delta Q + \int Tds$$

$$dA = Tds$$

$$\boxed{A = \int Tds}$$







- Area under the T-s diagram gives the heat interaction for an internally reversible process.
- Area enclosed by a cycle on a T-s diagram gives the net heat transfer if the cycle is internally reversible but according to 1st law net heat is equal to network and hence area enclosed by an internally reversible cycle represent net work interaction during the cycle.
- Area under T-s diagram has no meaning for a process which is not internally reversible (i.e, internally irreversible).
- Carnot cycle on T-s diagram is a rectangle.

Combined equations of 1st and 2nd law of thermodynamics

$$\delta Q = du + PdV$$

conditions
- closed system
- quasi-static swo
- $\Delta K.E = 0$ & $\Delta P.E = 0$

$$\frac{\delta Q}{T} = ds$$ For internally reversible

$$\boxed{\delta Q = Tds}$$

$$\boxed{Tds = du + Pdv} \quad — (1)$$

No condition is required for applying this eqn

$H = U + PV$

$$dH = \underbrace{du + Pdv}_{Tds} + vdP$$

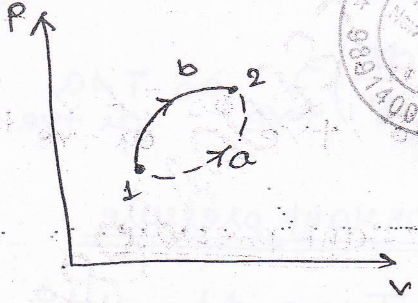
$dH = Tds + vdP$

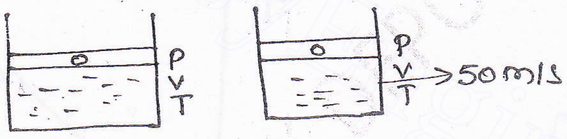
$$\boxed{Tds = dH - vdP}$$

$(dS)_a = \frac{\delta Q}{T} + (dS)_{gen}$

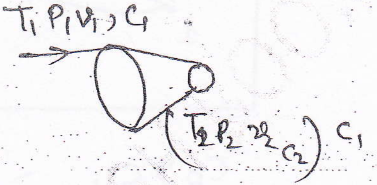
$(ds)_b = \frac{\delta Q}{T}$

$$\boxed{S_2 - S_1 = \frac{\delta Q}{T}}$$





Both have same entropy because kinetic energy is totally available energy and entropy is associated with totally unavailable energy.



Though Tds eqn were developed with an internally reversible process in mind undergone by a closed system but it is valid for both internally reversible and internally irreversible processes undergone by a closed or an open system.

Constant

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constant volume and constant pressure on T-s diagram

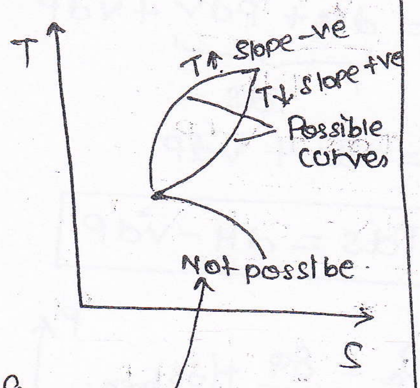
constant volume

$Tds = du + P\cancel{dv}^{\nearrow 0}$

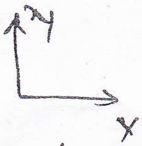
$Tds = C_v dT$

$$\boxed{\left(\frac{dT}{dS}\right)_V = \frac{T}{C_V}}$$

$\left(\frac{dT}{dS}\right)$ is +ve as T & C_V are +ve thus


T
T↑ slope -ve
T↓ slope +ve
Possible curves
Not possible
S

Slope = $\frac{dy}{dx}$



T↑ → slope decreasing

T↓ → " ↑

$du = C_v dT$

for any process at const vol.

$dh = C_p dT$

for any process at const vol.

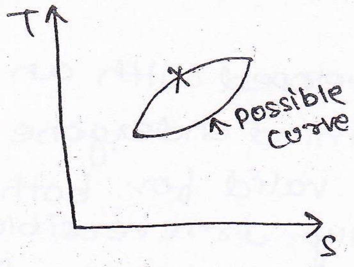
Constant pressure

$Tds = dh - vdP$

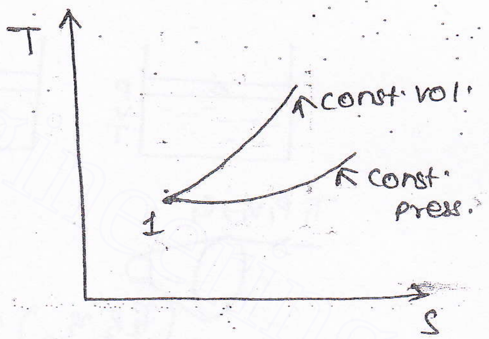
$Tds = dh$

$Tds = C_p dT$

$$\boxed{\left(\frac{dT}{ds}\right)_P = \frac{T}{C_p}}$$


T
possible curve
S

Combined curve for const vol & const press.


T
const vol.
const. press.
1
S

$C_p > C_V$

$\frac{1}{C_V} > \frac{1}{C_p}$

$$\boxed{\frac{T}{C_V} > \frac{T}{C_p}}$$

The slope of const vol curve is greater than constant pressure curve on T-s diagram.

Entropy change for an Ideal gas

$$\boxed{Tds = du + Pdv}$$

Air, helium, oxygen] ideal gas

(i) Ideal gas

$$du = C_v dT$$

$$pv = RT$$

$$ds = \frac{du}{T} + \frac{P}{T}\cdot dv$$

$$ds = \frac{C_v dT}{T} + \frac{R}{v}\cdot dv$$ (Integrating from 1 to 2)

(ii) C_v = constant

$$\boxed{s_2 - s_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}}$$

$$Tds = dh - v dP$$

$$ds = \frac{dh}{T} - \frac{v}{T} dP$$

(i) Ideal gas

$$dh = C_p dT$$

also

$$Pv = RT$$

$$ds = \frac{C_p dT}{T} - \frac{R}{P} dP$$

$$\boxed{s_2 - s_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_1}{P_2}}$$

when T, v is given

$$\boxed{S_2 - S_1 = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln \frac{V_2}{V_1}}$$

Trick

C_v is less than add something.

when P, T is given

$$\boxed{S_2 - S_1 = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln \frac{P_2}{P_1}}$$

C_p is more than subtract something.

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(Q) A closed system executes a reversible cycle consisting of six processes

1-2 → const. temp. (500K) heat addition of 1000 kj.

2-3 → Adiabatic expansion to 400K.

3-4 → Const. temp. (400K), heat addition of 800 kj.

4-5 → Adiabatic expansion to 300K.

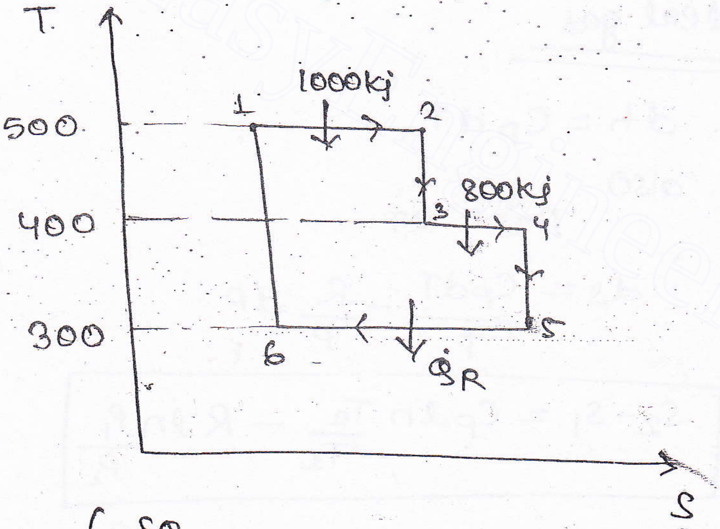
5-6 → const. temp. heat rejection.

6-1 → Adiabatic compression.

Represent the cycle on T-s diagram and find the net work done and efficiency of the cycle. Also draw P-V diagram for the cycle.

Sol

Heat rejection Entropy ↓



$$\oint \frac{\delta Q}{T} = 0$$

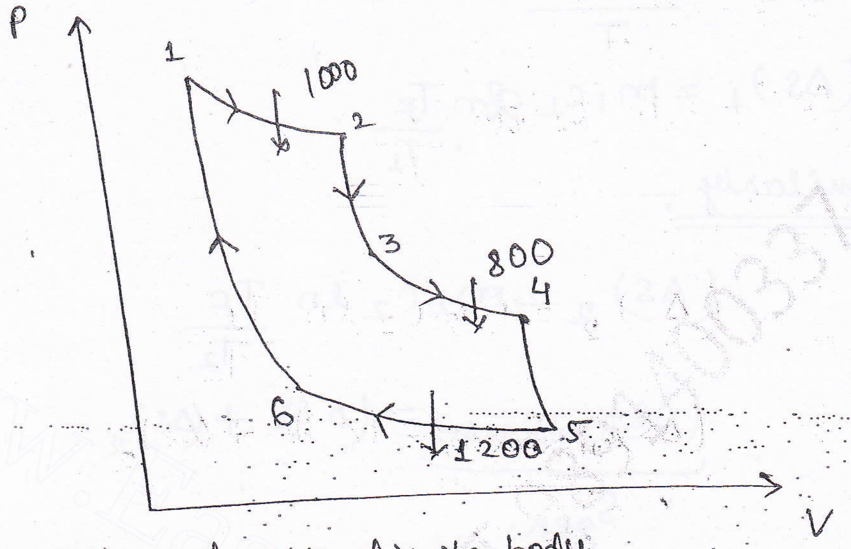
$$+\frac{1000}{500} + \frac{800}{400} - \frac{Q_R}{300} = 0$$

$$\boxed{Q_R = 1200 kj}$$

$$\Sigma Q = 1000 + 800 - 1200$$
$$= 600 KJ.$$

$$\Sigma Q = \Sigma W = 600$$

$$\eta = \frac{\Sigma W}{Q_{ad}} = \frac{600}{1800} = 0.33 = 33\%.$$



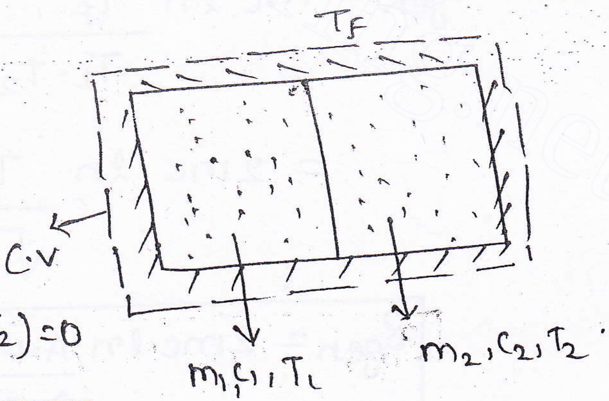
Entropy Analysis for the finite body

Type A : Mixing of two incompressible fluids

or

Two solid bodies brought in contact to attain a final common temp.

$$\cancelto{0}{\delta Q} = du + \cancelto{0}{\delta W}$$



$$du = 0$$

$$(du)_1 + (du)_2 = 0$$

$$m_1 C_1 (T_F - T_1) + m_2 C_2 (T_F - T_2) = 0$$

$$\boxed{T_F = \frac{m_1 C_1 T_1 + m_2 C_2 T_2}{m_1 C_1 + m_2 C_2}}$$

$$\underbrace{\Delta S_{universe}}_{S_{gen.}} = (\Delta S)_{sys.} + \cancelto{0}{(\Delta S)}_{surr.}$$

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$$(\Delta S)_{system} = (\Delta S)_1 + (\Delta S)_2$$

$$Tds = du + P\cancel{dv} \nearrow 0 \text{ (incompressible)}$$

$$\Rightarrow Tds = du = mcdT$$

$$ds = \frac{mcdT}{T}$$

$$(\Delta S)_1 = m_1 C_1 \ln \frac{T_F}{T_1}$$

Similarly,

$$(\Delta S)_2 = m_2 C_2 \ln \frac{T_F}{T_2}$$

$$\underbrace{(\Delta S)_{universe}}_{S_{gen}} = (\Delta S)_1 + (\Delta S)_2$$

$$\left\{ \begin{array}{l} \text{If } m_1 = m_2 \text{ \& } C_1 = C_2 \\ T_F = \frac{T_1 + T_2}{2} = A\cdot M \end{array} \right\} \quad G\cdot M = \sqrt{T_1 T_2}$$

$$S_{gen} = mc \ln \frac{T_F^2}{T_1 \cdot T_2}$$

$$= 2mc \ln \frac{T_F}{\sqrt{T_1 T_2}}$$

$$\boxed{S_{gen} = 2mc \ln \frac{A\cdot M}{G\cdot M}}$$

GM of n

$$= \sqrt[n]{T_1 T_2}$$

A-M

$$= \frac{T_1 + T_2 + \cdots + T_n}{n}$$

TYPE-B

The maxm work obtainable when two bodies initially at different temperature are allowed to exchange heat via a reversible heat engine to attain a common final temp.

Maxm work $= G.M = \sqrt{T_1 T_2}$

No work $= A.M$

$W = Q_1 - Q_2$

$\delta Q = du + \cancel{\delta W}^{\,0}$

$\delta Q = du = mc\,dT$

$Q_1 = m_1 c_1 \{T_f - T_1\}$

mag. of $Q_1 = m_1 c_1 \{T_1 - T_f\}$

Similarly,

$Q_2 = m_2 c_2 \{T_f - T_2\}$

$$\underbrace{(\Delta S)_{univ.}}_{S_{gen.}} = (\Delta S)_1 + (\Delta S)_2 + \cancelto{0}{(\Delta S)_E} + \cancelto{0}{(\Delta S)_{surr.}}$$

$= (\Delta S)_1 + (\Delta S)_2$

$T\,ds = du + \cancelto{0}{P\,dv}$ (incompressible)

$T\,ds = du = mc\,dT$

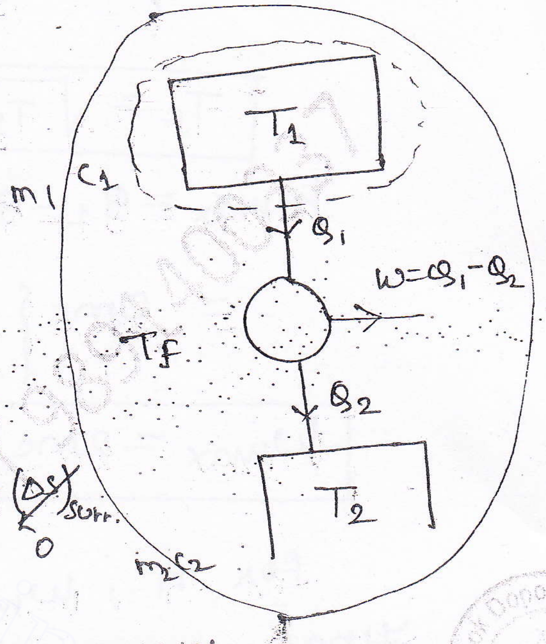
$ds = \frac{mc\,dT}{T}$

$(\Delta S)_1 = m_1 c_1 \ln \frac{T_f}{T_1}$

$(\Delta S)_2 = m_2 c_2 \ln \frac{T_f}{T_2}$

$S_{gen} = (\Delta S)_1 + (\Delta S)_2$

$$\boxed{\begin{array}{l} \text{If } W = W_{max} \\ \quad S_{gen} = 0 \end{array}}$$



$$m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2} = 0$$

If $m_1 = m_2$ & $c_1 = c_2$.

$S_{gen} = 0$

$$mc \left\{ \ln \frac{T_f^2}{T_1 T_2} \right\} = 0$$

$$\boxed{T_f = \sqrt{T_1 \cdot T_2} = G \cdot M}$$

$$W_{max} = Q_1 - Q_2$$

$$= 2mc \left\{ \frac{T_1 + T_2}{2} - T_f \right\}$$

$$\boxed{W_{max} = 2mc \{ A \cdot M - G \cdot M \}}$$

For n, $W_{max} = nmc \{ A \cdot M - G \cdot M \}$.

Final temp - varies from A.M to G.M.

- If n-identical bodies are brought in contact to attain a common final temp., then the final temp. ranges from geometric mean with Maximum delivery of work to A-M with zero delivery of work.

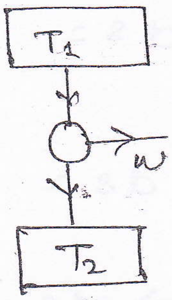
(Q) If an irreversible engine is installed b/w two identical bodies initially at diff temperatures than the final common temp. satisfy which of the following relations

(i) $T_f = \frac{T_1 + T_2}{2}$ (ii) $T_f = \sqrt{T_1 \cdot T_2}$

(iii) $T_f < \sqrt{T_1 \cdot T_2}$ ✓ iv) $\sqrt{T_1 \cdot T_2} < T_f < \frac{T_1 + T_2}{2}$

If $W_{max} \rightarrow$ out
Energy → Min^m.
Min^m tem G.M.
Max^m temp A.M.

$G.M < T_f < A.M$



(Q) If n-identical bodies are allowed to exchange heat via an engine then prove that final common temp. attained by the bodies satisfies

$$\left(T_1 \cdot T_2 \cdot T_3 \cdots T_N\right)^{1/N} \le T_f \le \frac{1}{N}\sum_{i=1}^{N} T_i$$

Sol^n → Reversible – Max^m work – Min^m temp – i.e, G.M

zero work – Max^m temp. i.e, A.M

(Q) show that for an ideal gas entropy is given by

$$S_2 - S_1 = C_p \ln\frac{V_2}{V_1} + C_v \ln\frac{P_2}{P_1}$$

Sol → $Tds = du + Pdv.$

$\boxed{du = C_v dT}$ —(I)

$Pv = RT$

For const vol.

$\boxed{v\,dP = R\,dT}$ —(II)

$\boxed{ds = \frac{du}{T} + \frac{P}{T}dv}$ —(III)

Putting (II) in (I), we get

$$du = C_v \cdot \frac{v}{R}\,dP$$

$$ds = \frac{du}{T} + \frac{P}{T}\,dv.$$

$$ds = \frac{C_v \cdot v \cdot dP}{TR} + \frac{P}{T}\,dv. \qquad [TR = Pv.$$

$$ds = \frac{C_v \cdot \cancel{v} \cdot dP}{P\cancel{v}} + \frac{P}{T}\,dv$$

$$\Rightarrow \cancel{ds}\; S_2 - S_1 = C_v \ln \frac{P_2}{P_1} + \frac{P}{T} \ln \frac{V_2}{V_1}.$$

Also,

$$dh = C_p\,dT$$

$$ds = \frac{dh}{T} - \frac{v}{T}\,dP,$$

$$ds = \frac{C_p \cdot P \cdot dv}{RT} - \frac{v}{T}\,dP.$$

$$\Rightarrow dS = \frac{C_p \cdot \cancel{p} \cdot dv}{\cancel{P}V} - \frac{V}{T}\,dP$$

$$\Rightarrow S_2 - S_1 = C_p \ln \frac{V_2}{V_1} - \frac{v}{T} \ln \frac{P_2}{P_1}.$$

$$S_2 - S_1 = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln \frac{V_2}{V_1}.$$

$$= C_v \ln\left(\frac{P_2V_2}{P_1V_1}\right) + \cancel{R}\,(C_p - C_v) \ln\left(\frac{V_2}{V_1}\right)$$

$$= C_v \ln \frac{P_2}{P_1} + \cancel{C_v \ln\left(\frac{V_2}{V_1}\right)} + C_p \ln\left(\frac{V_2}{V_1}\right) - \cancel{C_v \ln\left(\frac{V_2}{V_1}\right)}$$

$$\boxed{S_2 - S_1 = C_v \ln\left(\frac{P_2}{P_1}\right) + C_p \ln\left(\frac{V_2}{V_1}\right)}$$

19|11|13

Reversible work in a steady flow system

$$\boxed{W = -\int v\,dP}$$

① Steady state

$$h_1 + \frac{C_1^2}{2} + gz_1 + q = h_2 + \frac{C_2^2}{2} + gz_2 + w_{c.v}$$

(2) $\Delta K.E = 0$ & $\Delta P.E = 0$

$$h_1 + q = h_2 + w_{c.v}$$

$$q = h_2 - h_1 + w_{c.v}$$

$$\delta q = dh + \delta w_{c.v} \quad \text{—— (a)}$$

2nd Tds eqn

$$Tds = dh - vdp$$

$$\delta Q = \boxed{du + \delta W_b} + \delta W_o \ (\text{from } 1^{st} \text{ law})$$

(3) Internally reversible

$$ds = \frac{\delta Q}{T}$$

$$ds = \frac{\delta q}{T}$$

$$\boxed{\delta q = Tds}$$

Putting this in (a)

$$\boxed{Tds = dh + \delta w_{c.v}} \quad \text{—— ①}$$

2nd Tds eqn

$$Tds = dh - vdp \quad \text{—— ②}$$

from ① & ②

$$\delta W_{c.v} = -vdp$$

$$\boxed{W = -\int vdp}$$

To prove pv^{γ} = constant

① Ideal gas

$$S_2 - S_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

② Internally reversible.

③ Adiabatic.

$$0 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

$$\Rightarrow (C_p - C_v) \ln \frac{T_2}{T_1} = C_p \ln \frac{T_2}{T_1}$$

$$\Rightarrow (\gamma - 1) \ln \left(\frac{P_2}{P_1}\right) = \gamma \ln \left(\frac{T_2}{T_1}\right)$$

$$\Rightarrow \ln \left(\frac{P_2}{P_1}\right)^{\gamma-1} = \ln \left(\frac{T_2}{T_1}\right)^{\gamma}$$

$$\Rightarrow \left(\frac{T_2}{T_1}\right)^{\gamma} = \left(\frac{P_2}{P_1}\right)^{\gamma-1}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}}$$

→ pv^{γ} = const.

→ $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$\Rightarrow pv^{\gamma}$ = const.

used for both open as well as closed system.

Open system work in different situations

(1) Adiabatic (Reversible or irreversible)

(ii) steady state

(iii) $\Delta K.E = 0$ & $\Delta P.E = 0$.

$$h_1 + \overset{0\ (\text{Adiabatic})}{\cancel{q}} = h_2 + w_{c.v}$$

$$\boxed{w_{c.v} = h_1 - h_2}$$

(2) Adiabatic, Reversible, ideal gas

→ Steady State

→ K.E=0 & P.E=0.

$$w_{c.v} = h_1 - h_2$$

$$\boxed{w_{cv} = C_p(T_1 - T_2)}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}}$$

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(3) Polytropic, Reversible

→ steady state.

→ K.E=0 & P.E=0.

$$pv^n = const$$

$$w = -\int v dP$$

PV=const.(C)

$$\Rightarrow v = \left(\frac{C}{P}\right).$$

$$w = -\int_1^2 \left(\frac{C}{P}\right)^{1/n} dP \longleftarrow$$

$$w = C^{1/n} \int P^{-1/n} dP$$

$$w = -C^{1/n}\left[\frac{P_2^{-1/n+1} - P_1^{-1/n+1}}{-\frac{1}{n}+1}\right].$$

$$w = C^{1/n}\frac{n}{n-1}\left\{P_1^{-\frac{1}{n}+1} - P_2^{-\frac{1}{n}+1}\right\}$$

$$(P_1V_1^n)^{1/n} \qquad (P_2V_2^n)^{1/n}$$

$$\boxed{w = \frac{n}{n-1}\{P_1V_1 - P_2V_2\}}$$

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If $n = \gamma$

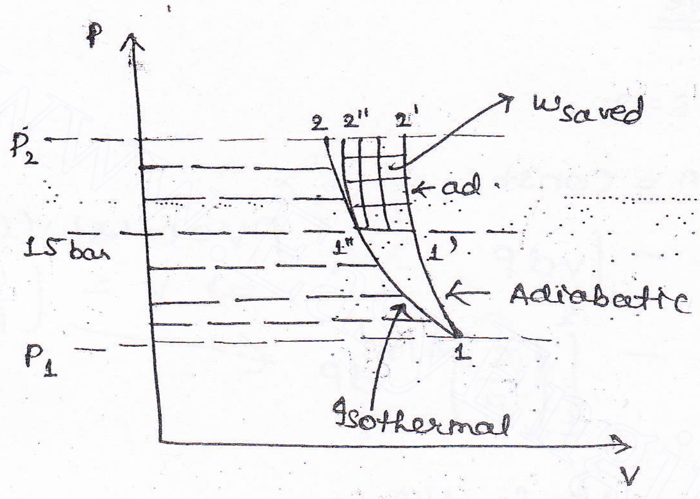
Ideal gas.

$$W = \frac{\gamma}{\gamma-1} R [T_1 - T_2].$$

$$\boxed{W = C_p (T_1 - T_2)}$$

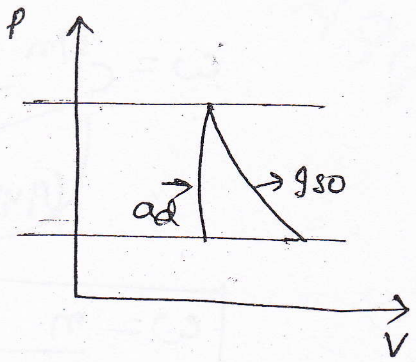
Multistage Compression, intercooling

Ideal intercooling - cool the substance to initial temp.


P
P_2
15 bar
P_1
2
2''
2'
1''
1'
1
W_{saved}
ad.
Adiabatic.
Isothermal
V

W_{saved} → work done by multistage compressor.
1-2'' → work done by single compressor.
1''-1'-2'-2'' → Multistage work done.

work is done in isothermal compression thus heat is rejected.



Entropy analysis for open system

$$(dS)_{c.v} = \frac{\delta Q}{T} + (\delta S)_{gen} + m_i s_i - m_e s_e$$

$$\left(\frac{dS}{dt}\right)_{c.v} = \frac{\delta \dot{Q}}{T} + (\delta S)_{gen} + \dot{m}_i s_i - \dot{m}_e s_e$$

Steady state $(\dot{m}_i = \dot{m}_e \Rightarrow \dot{m})$

$$0 = \frac{\delta \dot{Q}}{T} + (\delta \dot{S})_{gen} + \dot{m}(s_i - s_e)$$

⑧ Consider a steady state heat transfer through a 5m × 7m brick wall of a house of thickness 30cm on a day when the temp. of outdoors is 0°c, the house is maintained at 27°c. The temperature of the inner and outer surfaces of the brick wall are 20°c and 5°c, and the heat transfer through the wall is 1035W. Determine the rate of entropy generation in the wall and the rate of total entropy generation associated with this heat transfer.

Sol :- $q = 1035W$.

$(\delta S)_{gen} = ?$

$t = 30cm$, $T_2 = 5°c$, $T_1 = 20°c$.

$$\cancel{\delta q = dh + \delta w_{c.v}}$$

$$\cancel{q = h_2 - h_1 + w_{c.v}}$$

$$\cancel{1035 =}$$

$$\frac{\delta Q}{T} + (\delta S)_{gen} = \frac{dq}{T}$$

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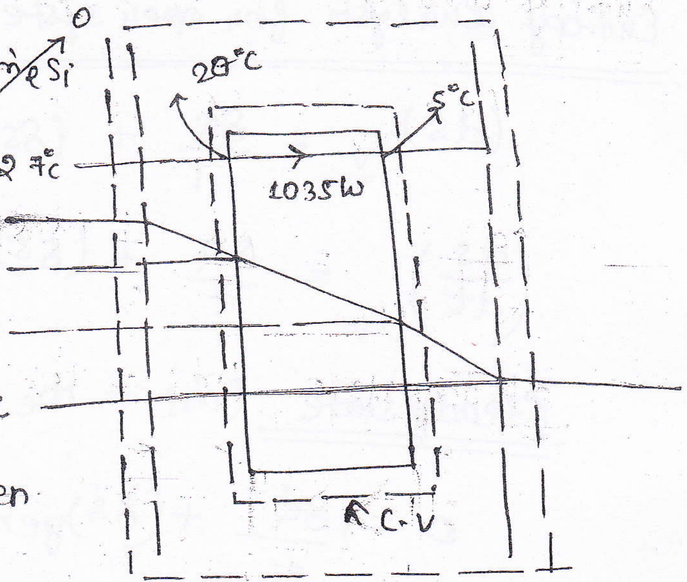
$$\cancel{\left(\frac{ds}{dt}\right)}_{C.V} = \frac{\delta \dot{Q}}{T} + (\delta \dot{s})_{gen} + \cancel{\dot{m}_i s_i}^{\,0} - \cancel{\dot{m}_e s_i}^{\,0}$$

0 (steady state)



$$0 = \frac{\delta \dot{Q}}{T} + (\delta \dot{s})_{gen}$$

$$0 = +\frac{1035}{293} - \frac{1035}{278} + (\delta \dot{s})_{gen}$$

$$(\delta \dot{s})_{gen} = -\frac{1035}{293} + \frac{1035}{278}$$

$$= 0.1905 \text{ W/K}$$

② $$\cancel{\left(\frac{ds}{dt}\right)}_{C.V} = \frac{\delta \dot{Q}}{T} + (\delta \dot{s})_{gen} + \cancel{\dot{m}_i s_i}^{\,0} - \cancel{\dot{m}_e s_e}^{\,0}$$

0 (steady state)

$$0 = +\frac{1035}{300} - \frac{1035}{273} + (\delta \dot{s})_{gen}$$

$$(\delta \dot{s})_{gen} = 0.341 \text{ W/K}$$

Available Energy (Energy, Availability & Irreversibility)

Available energy

It is the max^m useful work that can be obtained in a process in which system attains dead state.

Dead state

A system is said to be in dead state if it is ~~of homogeneous~~ in thermodynamic equilibrium with the surroundings.

Available energy is a function of

(i) Total energy.

(ii) state of the system.

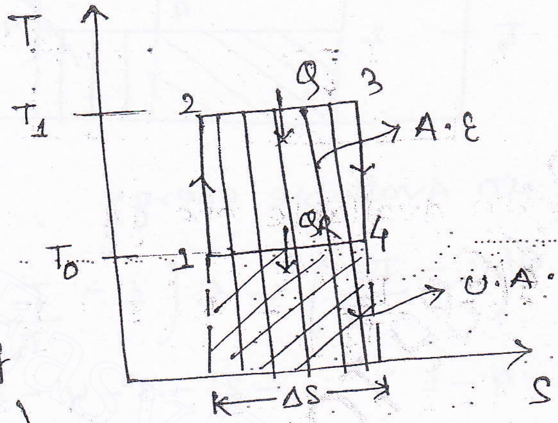
(iii) state of the surrounding.

(Irreversibility) $I = \{W_{max}\}_{useful} - \{W_{actual}\}_{useful}$

$I = W_{max} - W_{actual}$

I = A·E at process beginning − A·E at " end.

Rev. adia. comp.
→ T↑
Rev. adia. expa.
→ T↓



Here,
Available Energy
$= Q\left(1 - \frac{T_0}{T_1}\right)$

$$\boxed{\therefore \frac{W}{Q} = \left(1 - \frac{T_0}{T_2}\right)}$$

$A \cdot E = Q - Q_R$
$= Q - T_0(\Delta S)$

2→3

$ds = \frac{\delta Q}{T}$

$\Delta S = \frac{Q}{T_1}$.

$A \cdot E = Q - T_0 \times \frac{Q}{T_1}$

$$\boxed{A \cdot E = Q\left(1 - \frac{T_0}{T_1}\right)}$$

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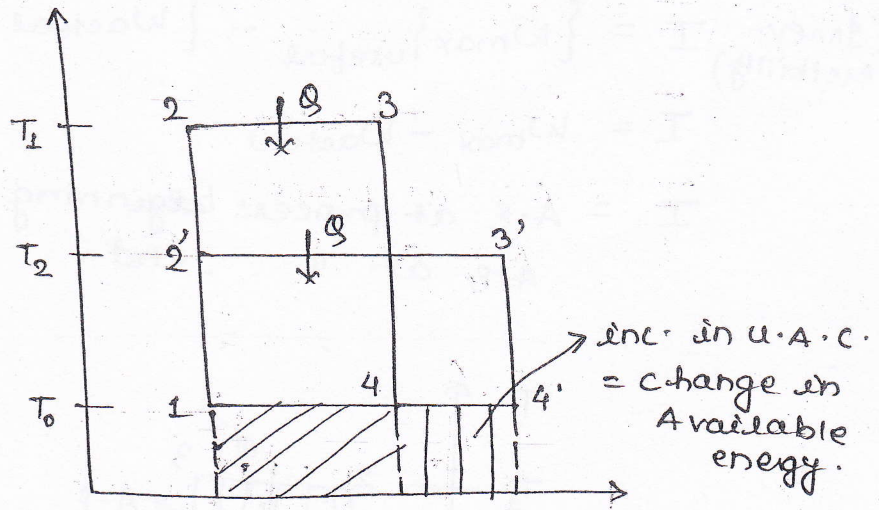
$Q, T_1 \to T_2$


T₁
T₂
T₀
2
3
Q
2'
3'
Q
1
4
4'
inc. in U.A.C.
= change in
Available
energy.

change in Available energy

$$= Q\left(1-\frac{T_0}{T_1}\right) - Q\left(1-\frac{T_0}{T_2}\right)$$

1 – 2 – 3 – 4 – 1 > 1 – 2' – 3' – 4' – 1.

because unavailable energy for this area
is > unavailable " " another area.

Availability function

Closed system

$$\delta Q = du + \delta W$$

$$(\delta W)_{sys} = (\delta Q)_{sys} - (dU)_{sys} \quad \text{— ①}$$

$$\boxed{\text{For } w = w_{max} \ (\Delta S)_{universe} = 0} \quad \text{— (ii)}$$

$$(\Delta S)_{uni} = (\Delta S)_{sys} + (\Delta S)_{surr}$$

$$0 = (\Delta S)_{sys} + (\Delta S)_{surr}.$$

$$(\Delta S)_{sys} = -(\Delta S)_{surro}.$$

A $\boxed{ds = \frac{\delta Q}{T}}$ → for internally reversible.

$$(ds)_{surro.} = \left(\frac{\delta Q}{T_0}\right)_{surro.}$$

$$(ds)_{sys.} = -(ds)_{surro.}$$

$$(ds)_{sys.} = -\frac{(\delta Q)_{surro.}}{T_0}$$

$$\boxed{(\delta Q)_{sys.} = -(\delta Q)_{surro.}}$$

$$(ds)_{sys.} = \frac{(\delta Q)_{sys}}{T_0}$$

$$(\delta Q)_{sys} = T_0 (ds)_{sys}$$

from ①

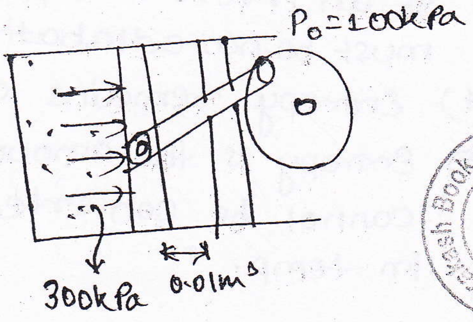
$$\underbrace{(\delta w)_{sys}}_{max.} = T_0 (ds)_{sys} - (dU)_{sys}$$

$$(\delta w)_{max} = T_0 (s_2 - s_1) - (U_2 - U_1).$$

$$\boxed{(\delta w)_{max} = (U_1 - T_0 s_1) - (U_2 - T_0 s_2)}$$

$$\boxed{\begin{aligned}(\delta w)_{\substack{max.\\ useful}} &= \delta w_{max.} - P_0 (V_2 - V_1).\\ &= (U_1 - T_0 s_1 + P_0 V_1) - (U_2 - T_0 s_2 + P_0 V_2)\end{aligned}}$$

$W_{atm} = 100 \times 0.01$
$= 1 kJ.$
$W_g = 300 \times 0.01$
$= 3 kJ.$
Net work $= 2 kJ.$



$$\{W_{max}\}_{useful} = W_{max} - P_0(V_2 - V_1)$$

$$= (U_1 - T_0S_1) - (U_2 - T_0S_2) - P_0(V_2 - V_1).$$

$$= \underbrace{(U_1 - T_0S_1 + P_0V_1)}_{\phi_1} - \underbrace{(U_2 - T_0S_2 + P_0V_2)}_{\phi_2}.$$

ϕ_1 = Avaibility f^n for state 1

ϕ_2 = Avaibility f^n for State 2

$\phi = U - T_0 S + P_0 V$ (combine ϕ can be written as)

$\phi = u + T_0 s + P_0 v$ [$u \rightarrow$ Internal energy per unit mass.

$v \rightarrow$ vol. per unit mass

$$\boxed{\phi = u - T_0 s + P_0 v + \frac{c^2}{2} + gz}$$

open system

$$\phi = h - T_0 s + \cancel{P_0 v} + \frac{c^2}{2} + gz$$

As this is open system

$$\boxed{\phi = h - T_0 s + \frac{c^2}{2} + gz}$$

True and False

(1) A reversible process is always internally reversible. T

(2) An isentropic process is always reversible adiabatic. F

(3) Entropy of an isolated system can never decrease. T

(4) A reversible adiabatic process is always isentropic. T

(5) Entropy generation in a process is ~~inversely~~ directly → T proportional to irreversibility of the process. F

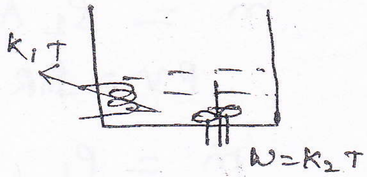
(6) If an irreversible process has to be isentropic it must be non-adiabatic. T

(7) Entropy remains conserved during a process. F

(8) Entropy is the amount of thermal energy that cannot be converted into work per unit fall in temp. T

W.B (P-17)

(29) $\delta\dot{Q} = d\dot{u} + \delta\dot{w}$



$$-k_1T = mc\frac{dT}{dt} - k_2 \cdot T$$

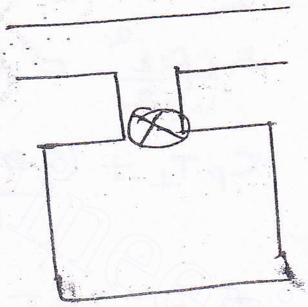
$$\Rightarrow \frac{(k_2-k_1)T}{mc} = \frac{dT}{dt}$$

$$\Rightarrow \int_0^t \frac{(k_2-k_1)}{mc}\,dt = \int_0^T \frac{dT}{T}$$

$$\Rightarrow \ln\frac{T}{T_0} = \frac{k_2-k_1}{mc} \times t$$

$$\Rightarrow T = T_0\, e^{(k_2-k_1/mc)t}$$ when time ↑ temp ↑ ⓑ

(30) $\left(\frac{du}{dt}\right) = \dot{m}_i h_i + \dot{Q} - \cancel{\dot{m}_e h_e}^{\,0} - \cancel{W_{c.v}}^{\,0}$



$$\left(\frac{dm}{dt}\right)_{c.v} = \dot{m}_i - \cancel{\dot{m}_e}^{\,0}$$

$$\frac{du}{dt} = \frac{dm}{dt} h_i + \dot{Q}$$

$$du = \int h_i \times \frac{dm}{\cancel{dt}} \times \cancel{dt} + \int \dot{Q}\,dt$$

$$\int du = h_i \int_1^2 dm + \cancel{Q}\,Q$$

$U_2 = U_2$ (remains const.)

$$0 = h_i(m_2 - m_1) + Q$$

$$0 = h_i(m_2 - m_1) - 2000$$

$$(m_2 - m_1) = \frac{2000}{h_i}$$

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(31) $\dot{m} = \rho_1 A_1 C_1 = \rho_2 A_2 C_2$

$\dot{m} = \rho_1 A_1 C_1$

$PV = mRT \Rightarrow P = \rho RT$.

$\dot{m} = \frac{P_1}{RT_1} \times A_1 \times C_1$

$\dot{m} = \frac{0.7 \times 100}{0.287 \times 57(330K)} \times 0.4 \times 200$

$= 59.1$ Kg/s.

(32) $\dot{m} = \rho_2 A_2 C_2$

$59.1 = \frac{P_2 \rightarrow}{\leftarrow RT_2} \times 0.6 \times C_2$

$C_2 = 0.2828 T_2$.

$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$

$C_p T_1 + \frac{(200)^2}{2} \times 10^{-3} = C_p \times T_2 + \frac{(0.2828 T_2)^2}{2} \times 10^{-3}$.

$T_2 = 345k$.

work transfer in adiabatic

$\cancel{\delta Q}^{0} = du + dw$

$\delta w = -du = u_1 - u_2$ (Point fn as only one pt. is obtained).

[But not a property]

True false (20/11/13)

(9) If an adiabatic process has to be isentropic it must be reversible. T

P.K Nag

(7.10)(a) $m = 600$ ~~k~~g
$C_p = 150\,J/K$, $T = 100°C$, $T_L = 8°C$.

$$(\Delta S)_{universe} = (\Delta S)_{lake} + (\Delta S)_{ball}$$

$$Tds = du + \cancel{Pdv}^{\,0}$$ (ball is copper ball thus it is incompressible).

$$Tds = (mc)dT$$
$\downarrow$ $c = J/K$.

$$Tds = 150\,dT \Rightarrow ds = \frac{150\,dT}{T} \Rightarrow \int ds = 150\int\frac{dT}{T}$$
$$\Rightarrow \Delta S = 150 \ln T_f/T_i$$

$$(\Delta S)_{ball} = 150 \ln \frac{T_f}{T_i}$$
$$= 150 \ln\left(\frac{281}{373}\right) = -42.483\,J/K.$$

Also,

$$\delta Q = du + \cancel{\delta W}^{\,0}$$
$$\Rightarrow \boxed{\delta Q = du = mcdT} \Rightarrow mcdT = Tds$$
$$ds = \frac{\delta Q}{T} \Rightarrow ds = \frac{du}{T}$$

$$ds = \frac{\delta Q}{T}.$$

$$(ds)_{lake} = \frac{\delta Q}{T}.$$

$$(\Delta S)_{lake} = \frac{+Q}{T_0} = \frac{+Q}{281}$$
$$= 49.110\,J/K.$$

$$(\Delta S)_{uni} = 6.637\,J/K.$$

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$$\overset{\nearrow \text{ball}}{\delta Q} = du$$

$$Q_{ball} = mc[T_f - T_i]$$

$$= 150\{100-8\}.$$

$$= 13800 \text{ j} = 13.8 \text{ kJ}$$

ⓑ $(\Delta S)_{universe} = (\Delta S)_{ball} + (\Delta S)_{lake}$.

$(\Delta S) = \dfrac{mgz}{281}$ (Potential energy of ball converted into thermal energy the temp. change in lake is zero as it is very large compared to lake].

$$= \frac{0.6 \times 9.81 \times 100}{281}$$

$$= 2.0946 \text{ J/K}.$$

(c) $\underset{0}{\cancel{\delta Q}} = du + \underset{0}{\cancel{\delta w}}$

$$\Rightarrow (du)_1 + (du)_2 = 0$$

$$\Rightarrow mc\{T_f - 100\} + mc\{T_f - 0\} = 0$$

$$\Rightarrow T_f = 50°C.$$

$(\Delta S) = \dfrac{\delta Q}{T}$ (If the substance is incompressible then $\delta Q = du$)

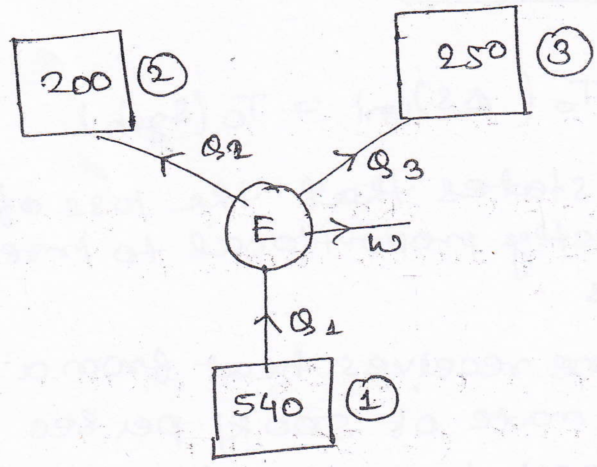
$$= \frac{du}{T} = \frac{mcdT}{T}$$

In case of finite body (temp. change) water entropy is in form of logarithm.

$$\Delta S = mc \ln \frac{T_f}{T_i}$$

$$S_{gen} = 2mc \ln \frac{A.M}{G.M}.$$

P.K Nag
7(15)



Solve.
7.15 with $U = cp^2$
7.36, 7.37

Let final temp. be T_f.

$$T_f = (T_1 \cdot T_2 \cdot T_3)^{1/3} = 300\text{K}.$$

$$\delta Q = du + \cancel{dw}^{\,0}$$

$$\delta Q = du = mc\,dT$$

$$W_{max} = Q_1 - Q_2 - Q_3 = 3mc\{A.M - G.M\}.$$

- Max^m & Max^m useful work is same in closed process.
- " " " " " ~~different~~ " closed cycle.

Note:

- In case of open system, max^m and max^m useful work are same since there is no role of atmospheric work.
- For a closed system working on a cycle, max^m and max^m useful ~~us~~ work are same since the work given to the atmosphere during the expansion process is recovered back during the compression process.

$$I = \{W_{max}\}_{useful} - \{W_{max}\}_{actual}$$

$$= W_{max} - W_{actual}$$

= A.E at process begenning − " " " end.

$\delta Q = du + dw$
δw_{act}.

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Gouy - stodola theorem

$$I = T_0 (\Delta S)_{uni} = T_0 (S_{gen})$$

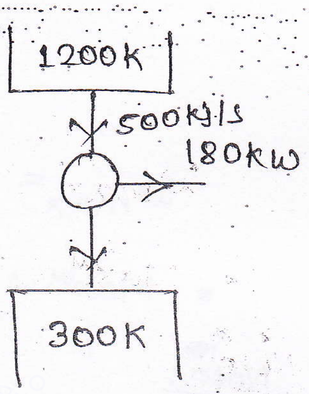
The theorem states that the loss of available energy is directly proportional to irreversibility in the process.

⑨ A heat engine receives heat from a source at 1200K at a rate of 500kj per sec and rejects the rest to a medium at 300K. The power output of the engine is 180kw. Determine the irreversibility rate for this process.

Sol →

$$I = T_0 (S_{gen})$$

$$= T_0 (\Delta S)$$



$$W_{max} = 500 \left(1 - \frac{300}{500}\right)$$

$$= 375 \text{ kw}.$$

$$I = W_{max} - W_{actual}$$

$$= 375 - 180$$

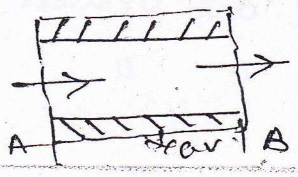
$$= 195 \text{ kw}.$$

⑨ Air is flowing steadily in an insulated pipe, the pressure and temp. at station A and station B are given below. Establish the dirn of flow of air.

	A	B
(KPa) Press	130	100
(°C) temp.	50	13

Sol

$$(\Delta S)_{uni} = (\Delta S)_{sys} + (\Delta S)_{surr}$$



open system as mass entering & leaving.

$$\cancel{\left(\frac{dS}{dt}\right)_{cv}} = \frac{\delta \dot{Q}}{T} + (\delta \dot{S})_{gen} + \dot{m}_i s_i - \dot{m}_e s_e$$

0 (steady state)

also $\dot{m}_i = \dot{m}_e = \dot{m}$

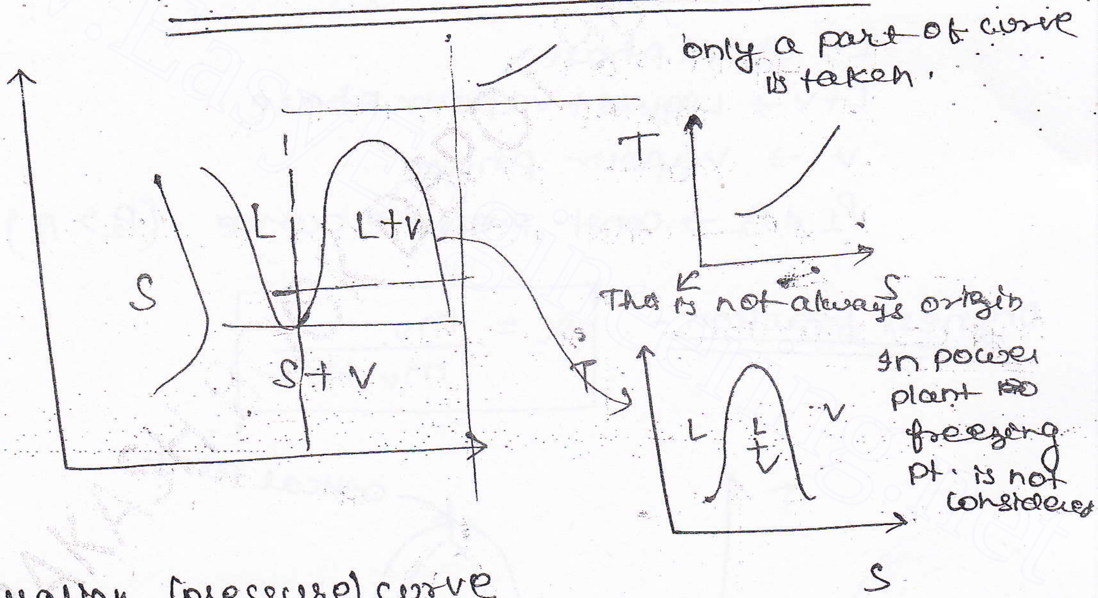
$$0 = 0 + (\delta \dot{S})_{gen} + \dot{m}(s_A - s_B)$$

$$(\delta S)_{gen} = \dot{m}(s_B - s_A) = \dot{m}\left\{C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right\}$$

$$= \dot{m}(-ve) = -ve$$

Entropy can never be −ve, thus assumed path is opposite.

Properties of Pure Substance


only a part of curve is taken.
T
S
L
L+V
S+V
This is not always origin
T
L
L/V
V
S
In power plant freezing pt. is not considered

Saturation (pressure) curve

This is experimentally obtained.

Saturated vapour → Just about to condense.

Saturated liquid → " " " vapourise.

Constant pressure curve – Also obtained experimentally.

" " " coincide in liquid region.

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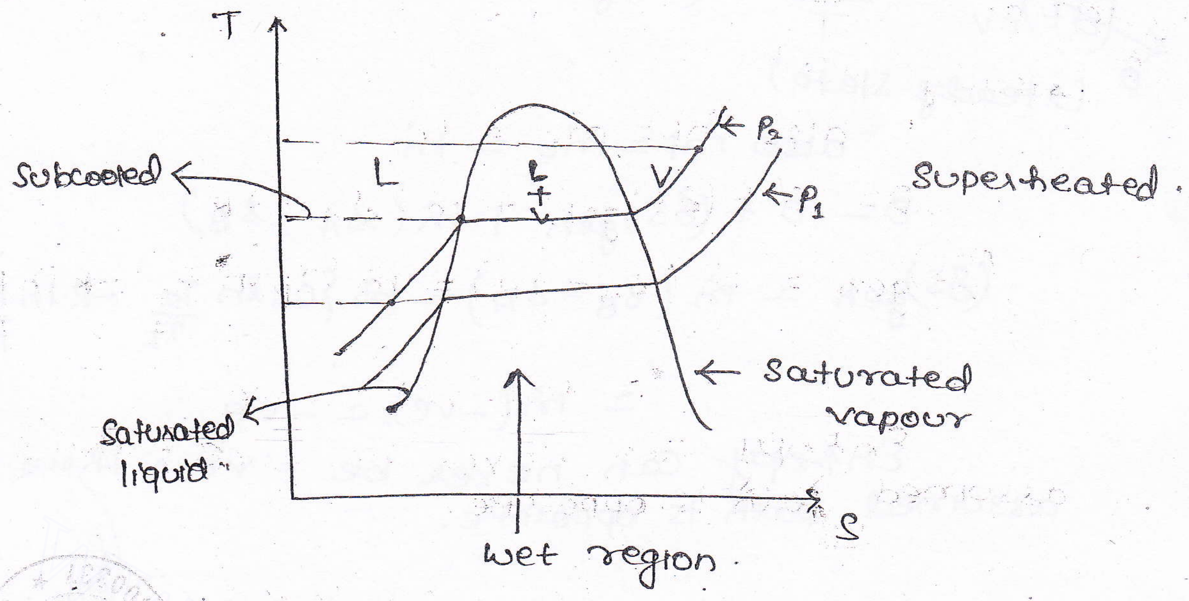

T
Subcooled
L
L + V
V
P_2
P_1
Superheated.
Saturated vapour
Saturated liquid
S
wet region.

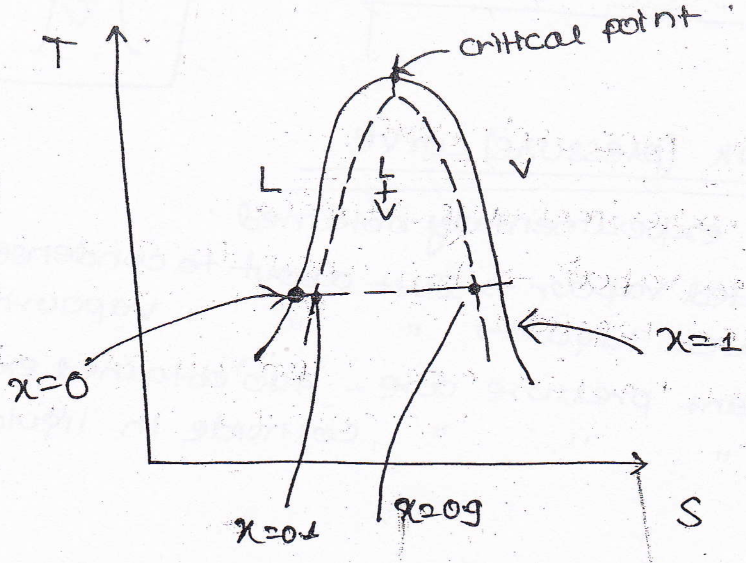
L → Liquid phase.

L+V → Liquid + vapour phase.

V → vapour phase.

P_1 & P_2 → const. pressure curve. ($P_2 > P_1$)

Dryness fraction - $\boxed{x = \frac{m_v}{m_v + m_l}}$

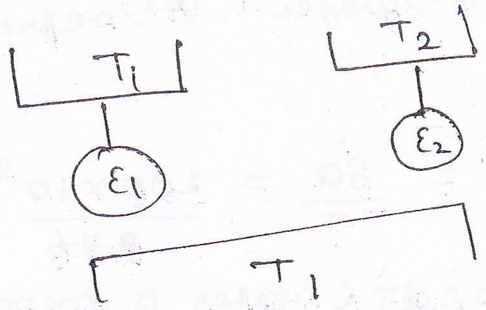

T
critical point
L
L + V
V
x=0
x=1
x=0.1
x=0.9
S

Subcooled region

A substance below its saturation temp. corresponding to its pressure is called subcooled liquid and the region is called subcooled region.

(Page-21) CWB

(10)



$T_2 < T_1$

$T_1 > T_2$

$\eta_1 > \eta_2$

same heat then ε_1 give more work

(12) $$\eta_{max} = 1 - \frac{T_L}{T_H} \Rightarrow \frac{T_L}{T_H} = 1 - \eta_{max}$$

$$COP = \frac{T_L}{T_H - T_L} = \frac{T_L/T_H}{1 - T_L/T_H}$$

$$= \frac{1 - \eta_{max}}{1 - (1 - \eta_{max})} = \frac{1}{\eta_{max}} - 1$$

Page 23

$s = f(t, v)$

incompressible, $v = \text{const.}$

$T = \text{const.}, \; dU = mcdT = 0.$

$u = \text{Const.}$

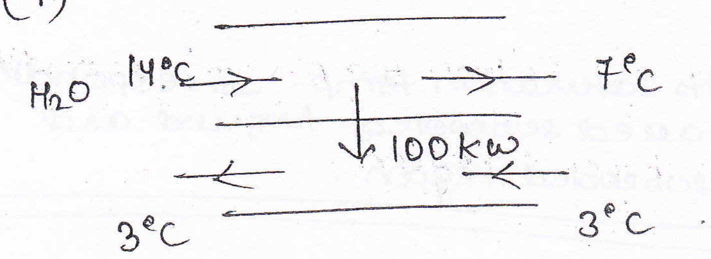
$s = \text{Const.}$ as T and v are const.

$h = u + pv$

$dh = \underset{0}{\cancel{du}} + p\underset{0}{\cancel{dv}} + vdp$

$dh = vdp = +ve.$

(7)



$$\underbrace{(\Delta S)_{uni}}_{S_{gen}} = (\Delta S)_{water} + (\Delta S)_{refre}$$

$$(dS)_{ref} = \frac{\dot{\delta Q}}{T} = \frac{100 \times 10^3}{276} = 362.3 \text{ W/K}$$

$$(dS)_{H_2O} = \frac{m\,c\,dT}{T} \text{ (water is incompressible)}$$

$$(\dot{dS})_{H_2O} = \dot{m} c \ln \frac{T_f}{T_i}$$

For water

$$\delta Q = du + \cancel{\delta w}^{\,0}$$

$$\delta \dot{Q} = d\dot{u} = \dot{m} c\, dT$$

water is going out thus,

$$-100 \times 10^3 = \dot{m} c \{7 - 14\}.$$

$$\Rightarrow \dot{m} c = \frac{-100 \times 10^3}{-7}$$

$$(\Delta S)_{H_2O} = \frac{100 \times 10^3}{7} \ln \frac{7}{-14}$$

$\boxed{21|11|13}$ when, $U = CT^2$.

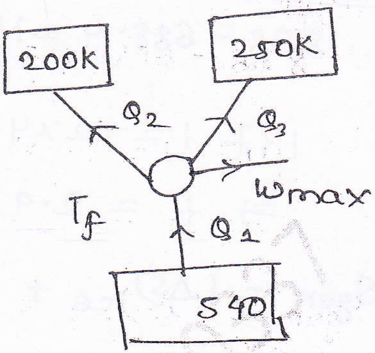
(7.15) For max^m work entropy generation must be zero.

$\delta Q = du + \cancel{\delta W}^{0} \Rightarrow \delta Q =$ ~~madT~~ du

$u = CT^2 \Rightarrow du = 2CTdT$.

$(\Delta S)_E = 0$, as the system works on a cycle.

If $U = mCT$ then max^m work is G.M otherwise A.M.



$$dS = \frac{\delta Q}{T} = \frac{2CT \cdot dT}{T}$$

$$\delta Q = du + \cancel{\delta W}^{0}$$

$$dS = 2CdT$$

$$A \cdot M = T_f = \frac{200 + 250 + 540}{3} = 330$$

$$(\Delta S)_1 = 2C \times [T_f - 200] = 2184\ J/K$$

$$(\Delta S)_2 = 2C \times [T_f - 250] = 1344\ J/K$$

$$(\Delta S)_3 = 2C \times [T_f - 540] = -3528\ J/K$$

$$\underbrace{(\Delta S)_{univ.}}_{S_{gen}} = (\Delta S)_1 + (\Delta S)_2 + (\Delta S)_3 + \cancel{(\Delta S)_E}^{0} + \cancel{(\Delta S)}^{0}_{surr.}$$

$$= 2C \left\{ 3T_f - \sum_{i=1}^{n} T_i \right] =$$

$W = W_{max}$

$S_{gen} = 0$

$$T_f = \frac{T_1 + T_2 + T_3}{3}$$

$$T_f = 330K$$

$$\delta Q = du + \cancel{\delta W}^{0}$$

$$\delta Q = 2CT \cdot dT$$

$$Q = 2C\frac{T^2}{2}\Big]_i^f$$

$$= 2C\,[T_f - T_i]$$

Find Q_1, Q_2, Q_3 by putting T_f & T_1, T_2, T_3 resp.

(7.36) Liq. 10kg 20°C $\quad \overset{\text{liq. water}}{20°C} \longrightarrow \overset{\text{liq. water}}{0°C} = 10 \times 4.18 \times 20 = 836\,kJ.$

ice. 2kg −5°C $\quad \underset{-5°C}{\text{ice}} \longrightarrow \underset{0°C}{\text{water}} = 2 \times 2.09 \times 5 + 2 \times 334$

$mcT + mL$

$= 688.9\,kJ.$

Difference

$836 - 688.4 = 147.1\,kJ.$

$(\Delta S)_{\cancel{}}$

$147.1 = 12 \times 4.18 \times \{t - 0\}.$

$\Rightarrow t = 2.932\,°C.$

0°C → 0°C.
Phase change.
$\cancel{for}\ ds = \frac{\delta Q}{T}$
$\int ds = \int \frac{dQ}{T}$
$\Rightarrow \int \Delta S = \frac{Q}{T}$

$S_{gen} = (\Delta S)_{ice} + (\Delta S)_{H_2O}$

$$(\Delta S)_{H_2O} = 10 \times 4.18 \ln \frac{273 + 2.92}{273 + 20}$$

$(\Delta S)_{ice}$

$$= \underbrace{2 \times 2.09 \ln\left[\frac{273+10}{273-5}\right]}_{-5°C\text{ ice} \rightarrow 0°C\text{ ice}} + \underbrace{\frac{2 \times 334}{273}}_{0°C\text{ ice} \rightarrow 0°C\text{ water}} + \underbrace{2 \times 4.18 \ln \frac{275.932}{273}}_{0°C\text{ water} \rightarrow 2.93°C\text{ water}}$$

$(\Delta S)_{ice} = 2.6134\,kJ/K.$

$(\Delta S)_w = -2.509\,kJ/K.$

$(\Delta S)_{uni} = 104.7\,J/K.$

(7.37) $P = I^2R.$

1 A, 1 sec.

$P = I^2R = (1)^2 \times 50$

$Q = I^2RT = (1)^2 \times 50 \times 1 = 50\,J.$

$du = mcdT, \quad \cancel{\delta Q}^{0} = du + \delta W$ (No heat came inside as the resistor is thermally insulated)

$du = -\delta W = -(-50)$

$= 50\,J.$

$50 = 5 \times 0.85\,(t - 10)$

$t = 21.76\,°C.$

$$ds = \frac{\delta Q}{T} = \frac{mc\,dT}{T}$$

$$(\Delta S)_{resistor} = mc \ln \frac{T_F}{T_i}$$

$$= 5 \times 0.85 \ln \left(\frac{273 + 21.76}{273 + 10} \right)$$

$$= 0.173 \text{ J/K.}$$

(7.33) $(\Delta S)_{resistor} = 0.$

$$(\Delta S)_{\cancel{uni}\ surr.} = \frac{\delta Q}{T} = \frac{I^2 R t}{T}$$

$$= \frac{(1)^2 \times 50 \times 1}{300} = 0.167\ \cancel{k}\ \text{J/k.}$$

(Eg) [7.3] ⓐ $(\Delta S)_{uni} = (\Delta S)_{ice} + (\Delta S)_{surr}$

$$(dS)_{surr} = \frac{\delta Q}{T_0}$$

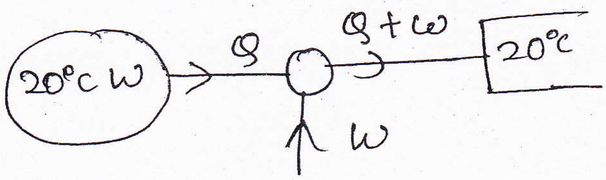
$$(\Delta S)_{surr} = \int \frac{\delta Q}{T_0} = \frac{Q}{T_0}$$

$$= \frac{\overbrace{\{1 \times 2.09 \times 5 + 333.3 + 1 \times 4.18 \times 20\}}^{Q}}{293}$$

$$(\Delta S)_{ice} = \underbrace{1 \times 2.09 \times \ln \frac{273}{268}}_{-5^\circ C\ ice\ \to\ 0^\circ C\ ice.} +$$

$$\frac{333.3}{273} + \underbrace{1 \times 4.18 \ln \frac{293}{273}}_{0^\circ C\ water\ \to\ 20^\circ C\ water}$$

ⓑ



for W_{min}, $S_{gen} = 0$.

$$\Delta S_{uni} = (\Delta S)_w + (\Delta S)_{surr.} + \cancelto{0}{(\Delta S)}_R$$

$(\Delta S)_w$

$$= 1 \times 4.18 \ln \frac{273+0}{273+20} - \frac{1 \times 333.3}{273} + \underbrace{1 \times 2.09 \ln \frac{268}{273}}_{0°C\ \text{ice} \rightarrow -5°C\ \text{ice}}$$

$$(\Delta S)_{surr.} = \frac{Q + W}{293}$$

Q. → It is same that we find in ⓐ.

Properties of pure Substance

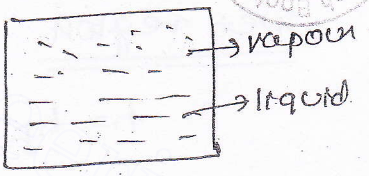
Energy required for phase change → latent heat.

Critical point

- It is the point where saturated liquid and saturated vapour curve meets.
- As the pressure increases the latent heat of vap. decreases and it becomes zero at critical point. liquid directly flashes into vapour.
- At critical point
- Degree of freedom zero at critical point.
- only one phase is present at critical point & it is neither liquid nor vapour.
- It is a fixed point i.e, degree of freedom is zero
- Dryness fraction is not defined at critical point as it is neither liquid nor vapour.

→ specific vol. of Mixture is average.

$$V = V_l + V_v$$



$$(m_v + m_l)\times v = m_l \times v_l + m_v \cdot v_v$$

$$v = \left(\frac{m_l}{m_v+m_l}\right)\cdot v_l + \left(\frac{m_v}{m_v+m_l}\right) v_v$$

(Avg) Specific vol. ← $\boxed{v = (1-x)v_f + \underset{\downarrow}{x} v_g}$ Dryness fraction.

$$\boxed{v = v_f + x(v_g - v_f)}$$

$$\downarrow$$

$$\boxed{v = v_f + x v_{fg}}$$

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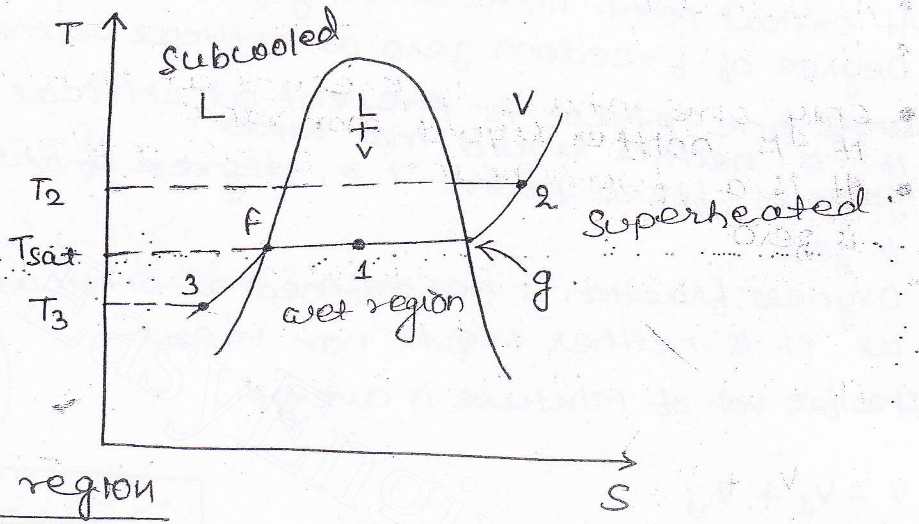
$$\boxed{s = s_f + x s_{fg}}$$

$$\boxed{u + u_f + x u_{fg}}$$

$$\boxed{h = h_f + x h_{fg}}$$

Enthalpy at various points

Energy supplied at const ~~temp~~ Press. → Enthalpy change.


T
Subcooled
L
L + V
V
T2
2
Superheated.
F
Tsat
1
3
g
T3
wet region
S

wet region

$$h = h_f + x h_{fg}$$

$$\boxed{Q_p = h_{fg} = L.H}$$

Superheatead

$$dh = C_p dT$$

$$h_2 - h_g = C_{p_v}(T_2 - T_{sat})$$

Subcooled

$$dh = C_{p_l} dT$$

$$h_f - h_3 = C_{pl}(T_{sat} - T_3)$$

$$h_3 = h_f - C_{p_{liq.}}(T_{sat} - T_3)$$

Entropy at various pts.

wet region

(1) $s_1 = s_f + x s_{fg}$

$$ds = \frac{\delta Q}{T}$$

$$\boxed{s_g - s_f = \frac{L.H.}{T_{sat}} = \frac{h_{fg}}{T_{sat}}}$$

Superheated

$$ds = \frac{\delta Q}{T} = \frac{C_{p_v} dT}{T}$$

$$s_2 - s_g = C_{p_v} \ln \frac{T_2}{T_{sat}}$$

$$\boxed{s_2 = s_g + C_{p_v} \ln \frac{T_2}{T_{sat}}}$$

Subcooled

$$ds = \frac{\delta Q}{T} = \frac{C_{p_l} dT}{T}$$

$$\boxed{s_f - s_3 = C_{p_l} \ln \frac{T_{sat}}{T_3}}$$

Ⓠ Saturated liquid at high pressure P_1 having enthalpy of 1000 kJ/kg is throttled to a lower pressure P_2. The enthalpy of saturated liquid and saturated, vap. at pressure P_2 are 800 kJ/kg and 2800 kJ/kg resp. Find the dryness fraction after throttling.

Sol $\quad x = \cancel{h = h_f + x h_{fg}}$.

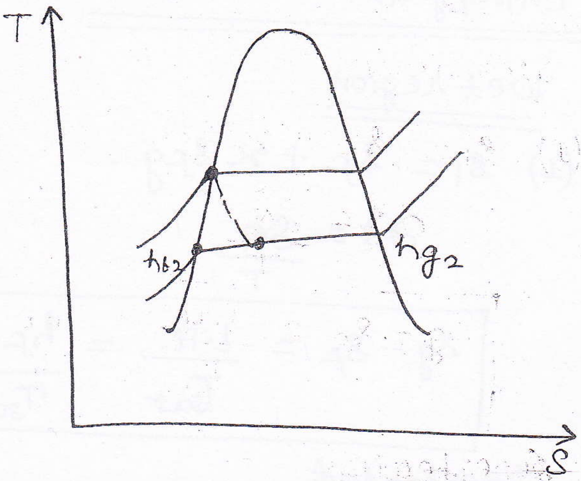
$$\Rightarrow \cancel{1000} = \cancel{800} +$$

In throttling

$h_1 = h_2$

$\Rightarrow 1000 = 800 + x(2800-800)$

$\Rightarrow \boxed{x = 0.1}$



(9) A cylinder with a movable piston contain 2kg of water and vapour mixture of dryness fraction 0.5 and at a pressure of 200KPa. Heat is now transfered to the vapour at constant pressure until the dryness fraction increases to 0.9. Find the total heat transfered in kJ.

P(KPa)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kgK)	s_g (kJ/kgK)
200	504.7	2706.7	1.5301	7.127

Sol -

$m = 2kg$, $x_1 = 0.5$, $P = 200KPa$;

$x_2' = 0.9$

- change in enthalpy - Energy supplied at const. pres

$h_1 = h_f + x\,h_{fg}$

$\Rightarrow h = 504.7 + 0.5(2706.7 - 504.7)$

$= 1605.7$ kJ

- change in internal energy supplied at const vol.

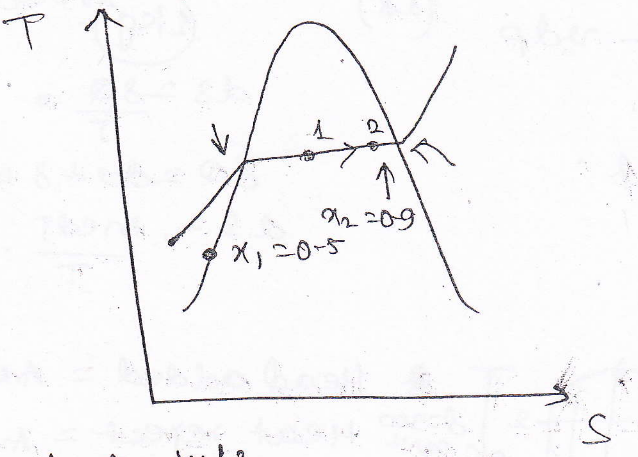
$h_2 = 504$

$= 2486.5$ kJ.

$\therefore Q_P = H_2 - H_1 = 2\{h_2 - h_1)$

$= 2\times(h_f + x_1 h_{fg}) - (h_f + x_1(h_{fg})\}$.

$= 2\times(x_2 - x_1)\{2706.7 - 504.7\}$.



Important points

- Entropy and internal energy at triple point is taken as zero.

  $s, u = 0$ at triple point for saturated liquid

  at 0.01°C.

- Specific volume of liquid very ↓

  $h \pm u + \boxed{P v \downarrow} \rightarrow$ negligable.

  for liquid

  $h \approx u$

  $h =$ slight +ve value

- The internal energy and the entropy of saturated liquid is taken as zero at triple point temp.
- At this state enthalpy has a slight +ve value
- Energy supplied at constant pressure is equal to change in enthalpy.
- Energy supplied at const. vol. is equal to change in internal energy

  (entropy)

W.B (Ch-5)

(15) . $Tds = dh - vdp$

$Tds = dh$

$\uparrow \frac{dh}{ds} = T \uparrow$

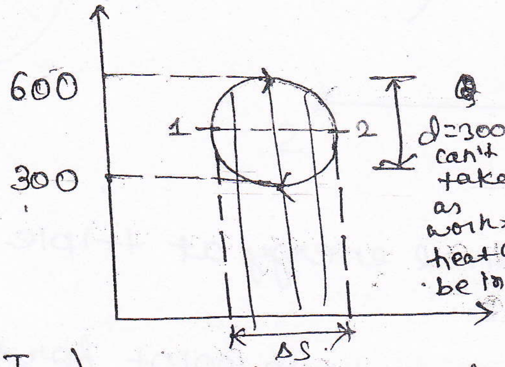
(18) $\boxed{1kg} \rightarrow 60°c \rightarrow 30°c$

$ds = \frac{\delta Q}{T}$

$\delta Q = du + \delta W$

$ds = \frac{mcdT}{T}$

(21)



d=300 can't taken as works heat can't be in terms of temp.

Heat added = $Area_{1-2}$

Heat reject = $Area_{2-1}$

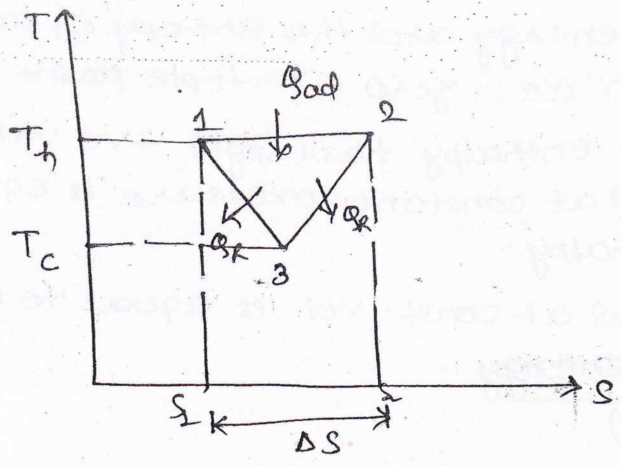
$\eta = \frac{W_{net}}{Q_{ad}}$

$= \frac{\frac{\pi}{4} \times (\Delta S)(600-300)}{\text{Area of semicircle } 1-2 + \text{Area of rectantangle}}$

$= \frac{1}{2}\left[\frac{\pi}{4} \times \Delta S(600-300)\right] + 450 \times \Delta S$

$\left(1 - \frac{T_c}{T_H}\right)$ valid only when only one temp - for T_c & T_H is given.

(24)



$\eta = \frac{W_{net}}{Q_{ad}}$

W_{net} = Area enclosed by the cycle
$= \frac{1}{2}(T_h - T_c) \times \Delta S$.

Q_{ad} = Area under rectangle $2\,2\,s_1\,s_2$

$= T_h \times \Delta S$.

(32) $\eta = \dfrac{W_{net}}{Q_{ad}} = \dfrac{W_{12} + W_{23} + W_{31}}{Q_{ad}}$

$P_1 V_1^{\gamma} = P_2 V_2^{\gamma} \Rightarrow V_1 = 2.6918\ m^3$.

$$W_{net} = \frac{P(V_2 - V_1) + 0 + \dfrac{P_3 V_3 - P_1 V_1}{\gamma - 1}}{Q_{ad}\,(\delta Q_{2-3})}.$$

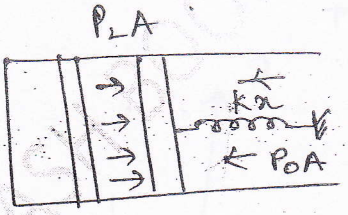
$Q_{ad} = \delta Q_{2-3} = du + \cancel{dw} \rightarrow 0$ (as const vol.

$\delta Q = du = m c_v (T_3 - T_2)$

$= \dfrac{mR}{\gamma - 1}(T_3 - T_2)$

$= \dfrac{P_3 V_3 - P_2 V_2}{\gamma - 1}$

(33)



$P_2 A = k \cdot x + P_0 \cdot A$.

$A x = V_2 - V_1$

$x = \dfrac{V_2 - V_1}{A} = \dfrac{0.003 - 0.002}{0.02}$

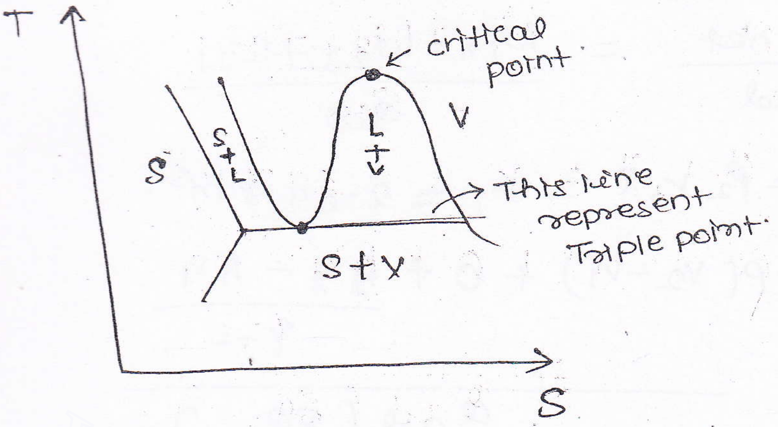
(34) $s_2 - s_1 = C_p \ln \dfrac{T_2}{T_1} - R \ln \dfrac{P_2}{P_1}$

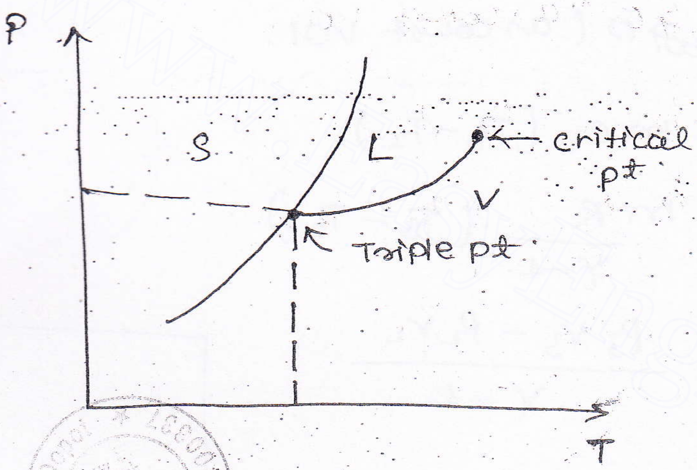
$\dfrac{P_1 V_1}{T_1} = \dfrac{P_2 V_2}{T_2} \Rightarrow \dfrac{T_2}{T_1} = \dfrac{P_2 V_2}{P_1 V_1}$

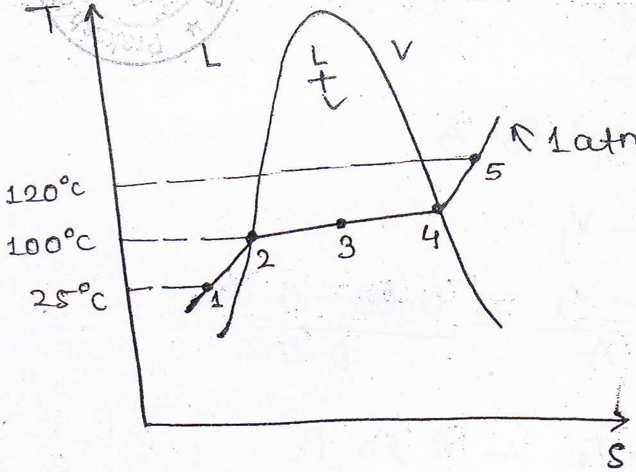
22|11|13

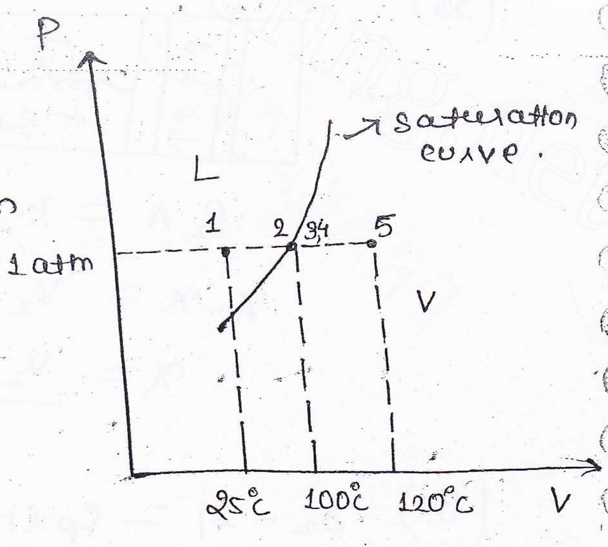
④ Pressure and temp diagram

- P-T → Triple pt. (pt.) otherwise line in any diagram h-s, T-s etc (contain phase change region).
- critical pt is only point due to presence of only one phase


T
critical point
S
S+L
L+V
V
This line represent Triple point
S+V
S


P
S
L
critical pt
V
Triple pt
T

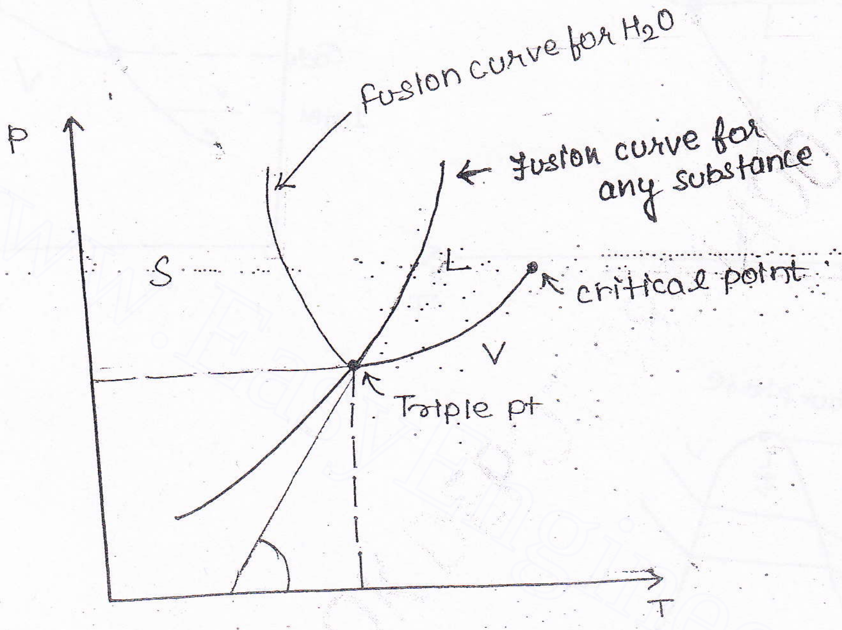

T
L
L+V
V
1 atm
120°c
100°c
25°c
1
2
3
4
5
S


P
saturation curve
L
1 atm
1
2
3 4
5
V
25°c
100°c
120°c
V

In P-V diagram all pts 2, 3 & 4 lies on same pt. because all lies at same pressure line ~~but~~ & temp. but at pt. 5 temp. is different thus it is at different pt. (but pressure is same).

- If out of the properties pressure, temp., volume, internal energy, enthalpy, enthalpy; if the graph is made between pressure and temp. then the phase change region is absent and the triple is a point.
- If the graph is made between any two properties other than pressure and temp. then the two phase region is present and triple point is a line.
- critical point is a point on every diagram.

tanθ < 90° (+ve)
slope (+ve)


fusion curve for H_2O
Fusion curve for any substance
P
S
L
critical point
V
Triple pt
T

$$\left(\frac{\partial P}{\partial T}\right)_{\text{@ fusion curve for general substance}} > 0$$

$$\left(\frac{\partial P}{\partial T}\right)_{\text{@ fusion curve for } H_2O} < 0$$

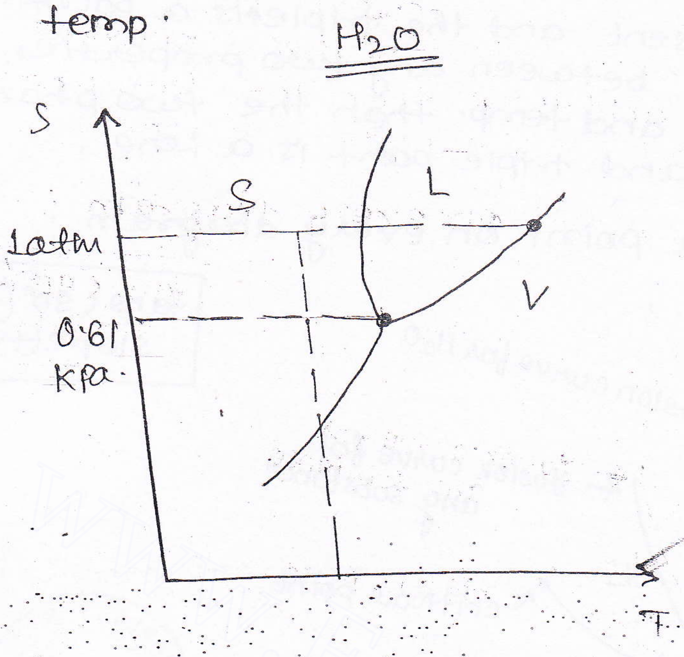
General substance

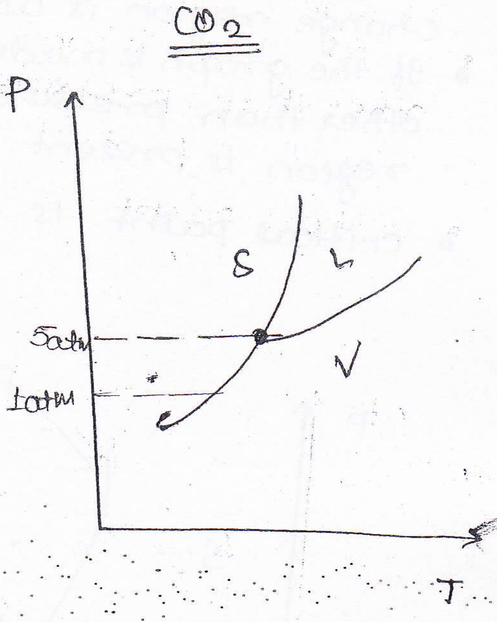
S → liquid expand
l → s contract

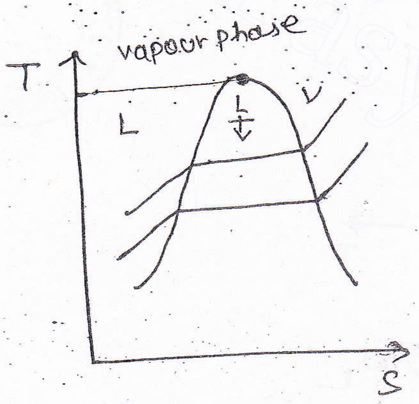
H_2O

S → liq. contract
liq. → S - expand

CO_2 and H_2O both can sublimate i.e, directly converted into vapour below its critical point temp.


H2O
S
S
L
1atm
0.61 KPa
V
T

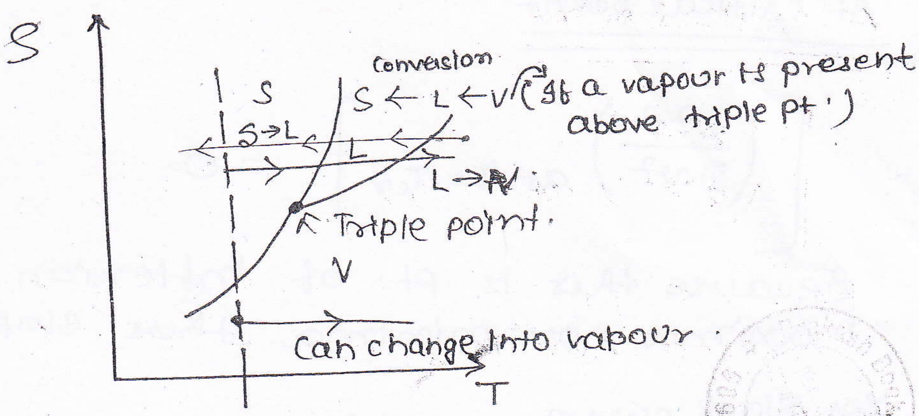

CO2
P
S
L
5atm
1atm
V
T


vapour phase
T
L
L↓V
V
S

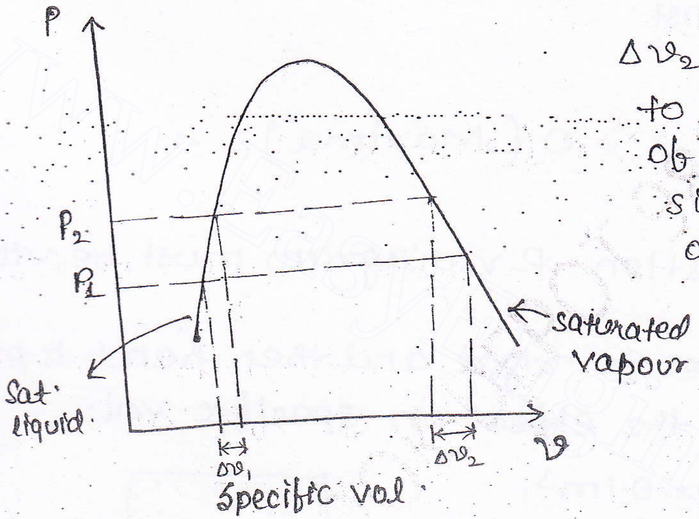
- If a substance is kept below its triple pt. pressure then on heating it will sublimate.
- If a substance is kept above its triple point pressure than on heating it will change into liquid then into vapour.
- A substance can not exist in liquid phase above critical point temp.

(Q) If a substance is present below its triple point temp than on heating it will

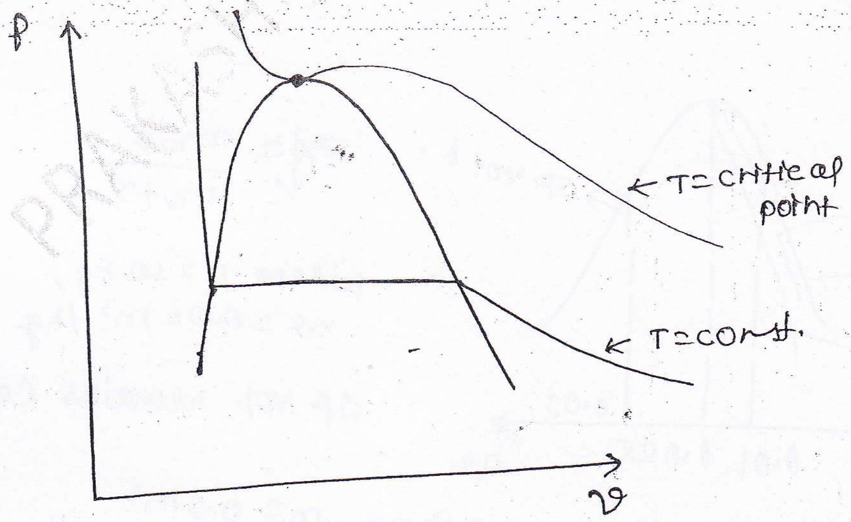
(a) sublimate (b) $s \to l \to V$ (c) will not change its phase at all [✓ (d) All of the above.]


S
S
S→L
L
L→V
conversion
S ← L ← V ('If a vapour is present above triple pt')
Triple point.
V
can change into vapour.
T

Pressure and specific volume diagram


P
P2
P1
Sat. liquid.
saturated vapour.
Δv1
Δv2
v
Specific vol.

Δv2 > Δv1 ~~bec~~ and due to this the nature of cure ~~ab~~ at one side is straight and on other side it is inclined.


P
T = critical point
T = const.
v

For blue line

Slope $\left[\left(\frac{\partial P}{\partial v}\right)_{at\ T=T_{cr}}\right] = 0$.

At critical point

$$\left[\left(\frac{\partial^2 p}{\partial v^2}\right)_{at\ T=T_{cr}}\right] = 0$$

Because this is pt. of inflexion i.e, neither maxima nor minima thus slope is zero.

For Black curve

$$\left(\frac{\partial p}{\partial v}\right)_{T=const.} = 0.$$

$$\left(\frac{\partial^2 p}{\partial v^2}\right)_{T=cr} > 0\ (Maxima)$$

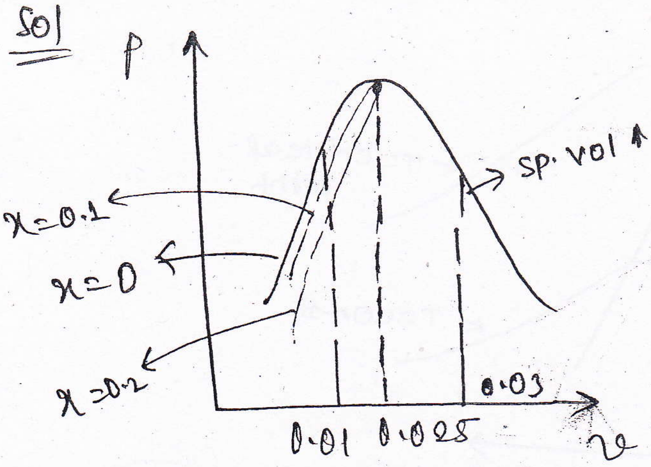
- Rigid vessel question P-v diagram must be visualised.

(Q) The given vessel is rigid and then heat is provided then what is the effect on specific vol.

$m = 10\,kg$, $V = 0.1\,m^3$

$v_a = 0.025\,m^3/kg.$

Sol



$$x\downarrow = \frac{m_v\downarrow}{m_v + m_l}$$

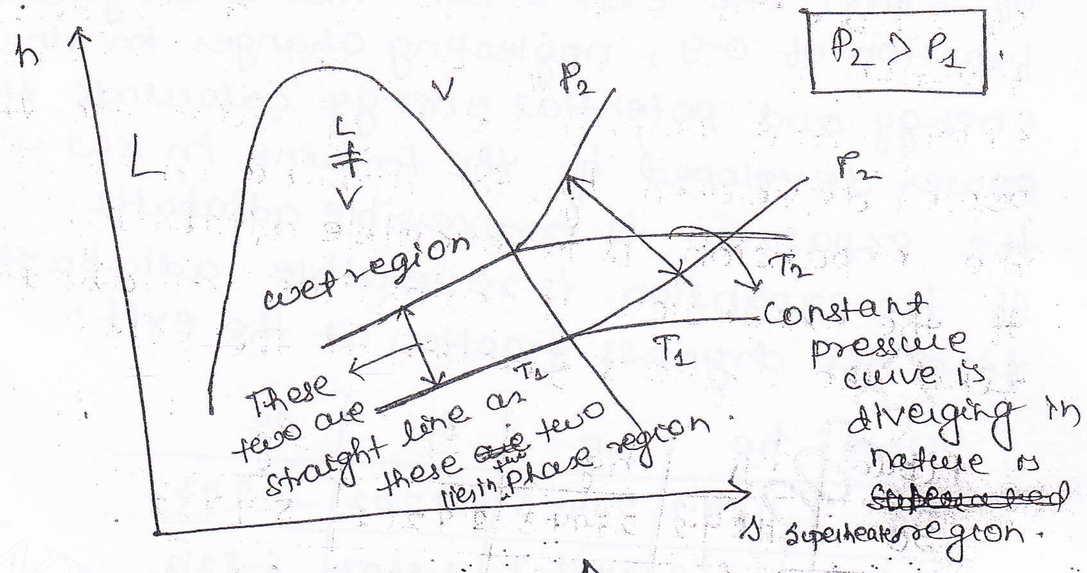
when n = 10 kg,
$v = 0.01\,m^3/kg,$

sp. vol. remains const.

- At left side of curve dryness fraction decreases thus from formula mass of vapour also decreases and mass of liquid increases.

when $m = 0.3\,m^3.$

Mollier diagram


P2 > P1
h
L
V
L + V
P2
P2
wet region
T2
constant pressure curve is diverging in nature in ~~superheated~~
T1
T1
These two are straight line as these ~~are~~ two lies in two phase region
s
superheated region

As Temp. is ↑ slope ↑.

P = const

$$T\,ds = dh - \cancelto{0}{v\,dp}$$

$$\Rightarrow T\,ds = dh \Rightarrow \boxed{\frac{dh}{ds} = T} \rightarrow \text{slope}$$

- h-s diagram is known as Mollier diagram and is use in power plant analysis.
- The vertical axis gives us the open system work (~~oper~~ 1st law of thermodynamics) and the horizonal axis gives the irreversibility in the process (2nd law of thermodynamics).
- Constant pressure curves are straight line in wet region and they are curves with increasing slope s in superheated region.
- Const. pressure curve diverge in superheated region.
- As we go away from the saturated curve the temp. become straight line as h is only a fn of enthalpy for ideal gas.

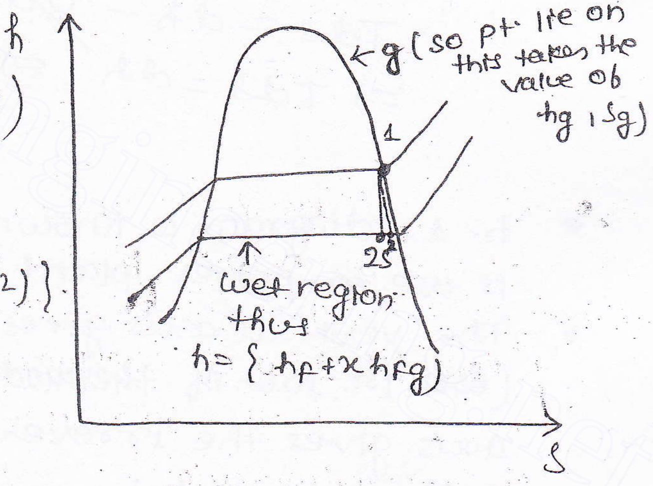
⑧ 5 kg/sec of dry saturated steam at a pressure of 50 bar expands in a turbine to a pressure of 5 bar. The exit steam has a dryness fraction of 0.9, neglecting changes in kinetic energy and potential energy calculate the power developed by the turbine in kW if the expansion is irreversible adiabatic. If the expansion is reversible adiabatic find the dryness fraction at the exit.

P(bar)	h_f	h_g	s_f	s_g
50	1154.2	2794.3	2.9202	5.9732
5	640.2	2748.7	1.8607	6.8213

$$w_{c.v} = h_1 - h_2$$

$$= h_g - \{h_f + x h_{fg})$$

$$= 2794.3 - \{640.2 + 0.9 (27943 - 640.2)\}$$


h
g (so pt lie on this takes the value of hg, sg)
1
2s
2
wet region thus h = {hf + x hfg)
s

$$P = \dot{m} w_{c.v}$$

$$= 1282.25 \text{ kW}.$$

1 – 2s :

$$s_1 = s_2 \Rightarrow 5.9732 = 1.8607 + x(6.8213 - 1.8607)$$

$$x = 0.829.$$

Thermodynamic Relation

Gibbs function :- $G = H - TS$

Helmholtz function :- $F = U - TS$

Theorem-1

$$Z = f(x, y)$$

$$dz = \underbrace{\left(\frac{\partial z}{\partial x}\right)_y}_{M} \cdot dx + \underbrace{\left(\frac{\partial z}{\partial y}\right)_x}_{N} \cdot dy$$

$Z \rightarrow$ is exact.

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

Theorem-2

$$Z = f(x, y)$$

$$\boxed{\left(\frac{\partial z}{\partial x}\right)_y \cdot \left(\frac{\partial x}{\partial y}\right)_z \cdot \left(\frac{\partial y}{\partial z}\right)_x = 0}$$

- During a real process the Gibb's f^n and Helmholz function decreases and attains a minimum value at the final equillibrium.

Maxwell relation

① $Tds = du + Pdv$

$du = Tds - Pdv$

$u \rightarrow$ exact diff.

$$\boxed{\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v}$$

(2) $T\,ds = dh - v\,dp$

$dh = T\,ds + v\,dP$

$$\boxed{\left(\frac{\partial T}{\partial P}\right)_s = \left(\frac{\partial v}{\partial s}\right)_P}$$

(3) $F = u \cancel{+} - Ts$

$df = du - T\,ds - s\,dT$

$df = -P\,dv - s\,dT$

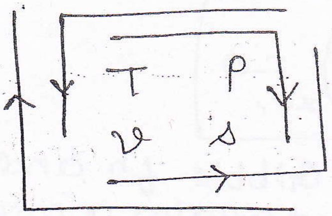
$$\boxed{+\left(\frac{\partial P}{\partial T}\right)_v = +\left(\frac{\partial s}{\partial v}\right)_T}$$

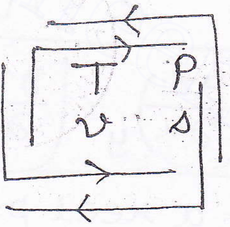
(4) $G = h - Ts$

$dG = \underbrace{dh - T\,ds}_{v\,dP} - s\,dT$

$dG = v\,dp - s\,dT$

$$\boxed{\left(\frac{\partial v}{\partial T}\right)_P = -\left(\frac{\partial s}{\partial P}\right)_T}$$





horizontal → +ve
vertical → −ve

$$\left(\frac{\partial v}{\partial s}\right)_p = \left(\frac{\partial T}{\partial P}\right)_s$$

$$\left(\frac{\partial P}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$

$$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial P}{\partial s}\right)_v$$

$$\left(\frac{\partial v}{\partial T}\right)_P = -\left(\frac{\partial s}{\partial P}\right)_T$$

Maxwell relations are used for determining change in entropy by measuring P, v & T.

Tds ~~equa~~' differential equation

$$s = f(T, v)$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_v \cdot dT + \left(\frac{\partial s}{\partial v}\right)_T \cdot dv$$

$$Tds = du + P\,\cancel{dv}^{\,0}$$

If v = const

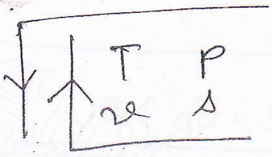
$$Tds = du = C_v dT.$$

$$\frac{ds}{dT} = \frac{C_v}{T}$$

$$\left(\frac{ds}{dT}\right)_v = \frac{C_v}{T}$$

from maxwell eqn

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v$$



$$ds = \frac{C_v}{T} \cdot dT + \left(\frac{\partial P}{\partial T}\right)_v \cdot dv$$

$$\boxed{T \cdot ds = C_v dT + T\left(\frac{\partial P}{\partial T}\right)_v \cdot dv}$$ 1st Tds eqn.

$$s = f(T, P)$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_P \cdot dT + \left(\frac{\partial s}{\partial P}\right)_T \cdot dP.$$

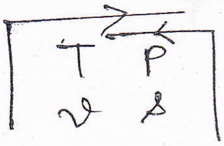
$$Tds = dh - v\,\cancel{dP}^{\,=0}.$$

P=const

$$Tds = dh = C_p dT.$$

$$\frac{ds}{dT} = \frac{C_p}{T}$$

$$\left(\frac{\partial s}{\partial T}\right)_p = \frac{C_p}{T}$$



$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P$$

$$ds = \frac{C_p}{T} \cdot dT \cdot \left(\frac{\partial v}{\partial T}\right)_P \cdot dP \cdot$$

$$\boxed{Tds = C_p dT - T\left(\frac{\partial v}{\partial T}\right)_P \cdot dP}$$ 2nd Tds eqn.

To prove $C_p > C_v$

From 2-Tds eqns

$$C_v dT + T\left(\frac{\partial P}{\partial T}\right)_v \cdot dv = C_p dT - T\left(\frac{\partial v}{\partial T}\right)_P \cdot dP$$

$$(C_p - C_v) dT = T\left\{\left(\frac{dP}{dT}\right)_v \cdot dv + \left(\frac{\partial v}{\partial T}\right)_P \cdot dP\right\}.$$

$$\boxed{dT = \frac{T}{C_p - C_v}\left\{\left(\frac{\partial P}{\partial T}\right)_v dv + \left(\frac{\partial v}{\partial T}\right)_P \cdot dP\right\}} \quad \text{—①}$$

$$T = f(P, v)$$

$$\boxed{dT = \left(\frac{\partial T}{\partial P}\right)_v \cdot dp + \left(\frac{\partial T}{\partial v}\right)_P \cdot dv} \quad \text{—②}$$

$$\boxed{\left(\frac{\partial T}{\partial P}\right)_v \cdot \left(\frac{\partial P}{\partial v}\right)_T \cdot \left(\frac{\partial v}{\partial T}\right)_P = -1} \quad —③$$

Comparing coefficient of dP in ① & ②

$$\frac{T}{C_p - C_v}\left(\frac{\partial v}{\partial T}\right)_P = \left(\frac{\partial T}{\partial P}\right)_v$$

from eqn ③

$$\left(\frac{\partial P}{\partial T}\right)_v = -\left(\frac{\partial P}{\partial v}\right)_T \cdot \left(\frac{\partial v}{\partial T}\right)_P$$

$$C_p - C_v = \underset{\substack{\downarrow\\ -ve}}{-}\;\underset{\substack{\downarrow\\ \text{absolute}\\ \text{thus always}\\ +ve}}{T}\;\underbrace{\left\{\left(\frac{\partial v}{\partial T}\right)_P\right\}^2}_{+ve} \times \underbrace{\left(\frac{\partial P}{\partial v}\right)_T}_{-ve} = +ve.$$

Thus, $\boxed{C_p > C_v}$

Coefficient of volume expansivity (β)

$$\boxed{\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P}$$

Isothermal compressibility (K_T)

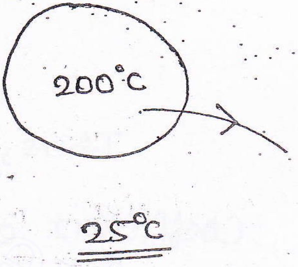
$$\boxed{K_T = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T}$$

$$\boxed{C_p - C_v = \frac{TV\beta^2}{K_T}}$$

① ⑧ A solid aluminium sphere of 0.1m dia initially at 200°c is allowed to cool to ambient temp. of 25°c. The density of aluminium is 2700 kg/m³ and the specific heat is 0.9 KJ/kgk. find the irreversibility in kj.

② ⑧ An adiabatic cylinder of 10 m³ volume is divided into two compartments A and B each of volume 6m³ and 4m³ by a thin sliding partition. Initially the compartment A is filled with air at 6 bar, 600K. while there is vacuum in compartment B. Suddenly the partition is removed and fluid in compartment A expands freely. calculate the irreversibility of the ~~processk~~ in kJ, take atm. pressure at 1 bar and atm. temp as 300k.

① $I = T_0 (\Delta S)_{univ}$



$(\Delta S)_{univ} = (\Delta S)_{ball} + (\Delta S)_{surr.}$

$(\Delta S)_{alu.} = mc \ln \frac{T_f}{T_i}$

$\rho = \frac{m}{V} = 2700 \times \frac{4}{3} \pi \left(\frac{0.1}{2}\right)^3 = 1.414$ kg/m3.

$(\Delta S)_{Al} = 1.414 \times 0.9 \ln \frac{298}{473}$.

$(\Delta S)_{surr.} = \int + \frac{\delta Q}{T_0} = + \frac{Q}{T_0} = \frac{m \times c (200-25)}{298}$

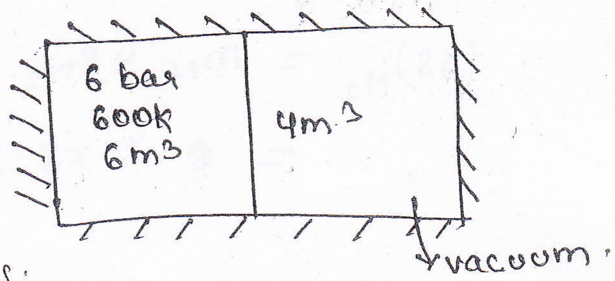
$= 0.7473$ kj/K.

$I = 47.49$ kj

⑨ $T_0 = 300K$

$I = T_0(\Delta S)_{univ}$

$(\Delta S)_{univ.} = (\Delta S)_{sys} + \cancelto{0}{(\Delta S)}_{surr.}$



$= (\Delta S)_{sys} = m(\Delta S)_{sys}$.

(Free expansion)

$(\Delta S)_{sys} = C_v \ln \cancelto{0}{\frac{T_2}{T_1}} + R \ln \frac{V_2}{V_1}$

$= 0.287 \ln \frac{10}{6} = 0.1466$

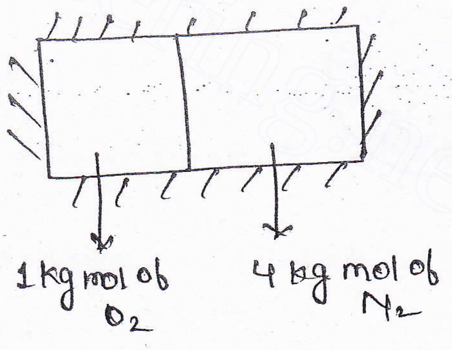
$m = \frac{P_1 V_1}{R T_1} = \frac{600\times 6}{0.287\times 600} = 20.905$ kg

$(\Delta S)_{univ} = m(\Delta S)_{sys} = 20.905 \times 0.1466$

Entropy generation due to mixing of Ideal gases

$(\Delta S)_{O_2}$

200kPa
300k



$= C_p \ln \cancelto{0}{\frac{T_2}{T_2}} - R \ln \frac{P_2}{P_1}$

$= -R \ln \frac{\left(\frac{1}{1+4}\right)\times 200}{200}$ → mole fraction of O_2

$= R \ln 5$

$(\Delta s)_{O_2} = m\times(\Delta s)_{O_2} = m\times R\ln 5$

$= m\times\frac{\bar{R}}{M}\ln 5 = n_{O_2}\times\bar{R}\ln 5$

$= 1\times 8.314 \ln 5$

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Similarly,

$$(\Delta S)_{N_2} = m_{N_2} \times R_{N_2} \times \ln \frac{5}{4}$$

$$= \cancel{0}\ 4 \times 8.314 \ln \frac{5}{4}.$$

Reversible

Quasi-static

Ideal fluid

Ideal flow

Assume friction less to elimenate

23 | 11 | 13

Energy equation

$$Tds = du + Pdv$$

$$du = Tds - Pdv$$

$$Tds = C_v dT + T\left(\frac{\partial P}{\partial T}\right)_v dv$$

$$du = C_v dT + \left\{T\left(\frac{\partial P}{\partial T}\right)_v - P\right\} dv$$

Ideal gas

$$Pv = RT$$

$$\left(\frac{\partial P}{\partial T}\right)_v \cdot v = R$$

$$\left(\frac{\partial P}{\partial T}\right)_v = \frac{R}{v}$$

$$T\left(\frac{\partial P}{\partial T}\right)_v = \frac{RT}{v} = P$$

$$\boxed{du = C_v dT} \Rightarrow \text{Ideal gas}$$

Imp Joule thomson coefficient (μ)

$$\mu = \left(\frac{\partial T}{\partial P}\right)_h$$

$$Tds = dh - vdP$$

$$dh = Tds + vdp$$

$$Tds = C_p dT - T\left(\frac{\partial v}{\partial T}\right)_p \cdot dP$$

$$dh = C_p dT - T\left(\frac{\partial v}{\partial T}\right)_p dP + vdP$$

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$$dh = C_p dT - \left\{ T\left(\frac{\partial v}{\partial T}\right)_P - v \right\} dP \quad \text{——} \quad ①$$

For ideal gas

$$Pv = RT$$

$$P\left(\frac{\partial v}{\partial T}\right)_P = R$$

$$T\left(\frac{\partial v}{\partial T}\right)_P = \frac{RT}{P} = v.$$

∴ ideal gas

$$\boxed{dh = C_p dT}$$

h = constant.

$$0 = C_p dT - \left\{ T\left(\frac{\partial v}{\partial T}\right)_P - \partial v \right\} dP.$$

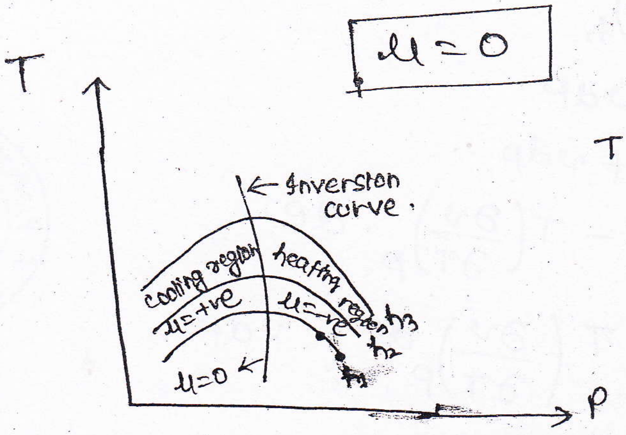
$$C_p dT = \left\{ T\left(\frac{\partial v}{\partial T}\right)_P - \cancel{\partial}\, v \right\} dP.$$

$$\left(\frac{dT}{dP}\right) = \frac{1}{C_p}\left\{ T\left(\frac{\partial v}{\partial T}\right)_P - v \right\}.$$

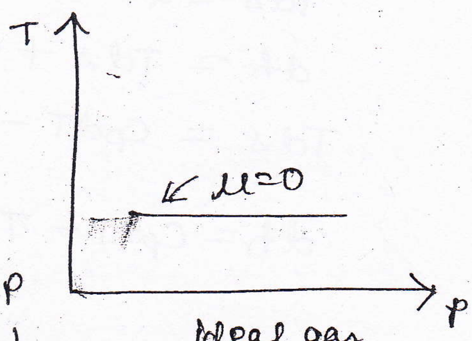
$$\boxed{\mu = \left(\frac{\partial T}{\partial P}\right)_h = \frac{1}{c_p}\left\{ T\left(\frac{\partial v}{\partial T}\right)_P - v \right\}}$$

but if ideal gas $T\left(\frac{\partial v}{\partial T}\right)_P = v.$

$$\boxed{\mu = 0}$$


T
Inversion curve.
cooling region
μ=+ve
heating region
μ=−ve
h3
h2
h1
μ=0
p

General Substance (Real gas)



Ideal gas

In two phase region $\mu = +ve$ as pressure ↑ temp. ↑ thus $\frac{\partial P\uparrow}{\partial T\uparrow} = +ve\uparrow$.

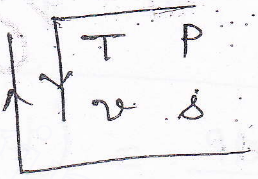
- μ is +ve in the cooling region and −ve in the heating region. For ideal gas μ is zero everywhere and hence there is no heating or cooling region.
- For real gases $\mu = 0$ everywhere on the inversion curve.
- If ideal gas is used as refrigerant throttling is never used for pressure reduction instead isentropic expander or turbine is used.

[Piston-cylinder arrangement]

Clausius-clapeyron Equation

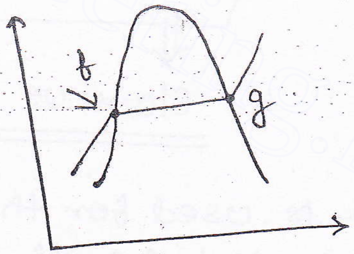
using Maxwell eqn

$$\left(\frac{\partial P}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$



During phase change

$P = f(T)$ only



$$\left(\frac{\partial P}{\partial T}\right)_v = \frac{dP}{dT}$$

Also

$$\left(\frac{\partial s}{\partial v}\right)_T = \frac{s_g - s_f}{v_g - v_f}$$

$$\left(\frac{dP}{dT}\right) = \frac{s_g - s_f}{v_g - v_f}$$

$$s_g - s_f = \frac{L \cdot H}{T_{sat}}$$

$$\boxed{\frac{dP}{dT} = \frac{L \cdot H}{T_{sat}(v_g - v_g)}}$$

$\Downarrow$

Clepeyron equation.

$$v_g >> v_f$$

$$v_g - v_f \simeq v_g$$

If vapour is ideal gas

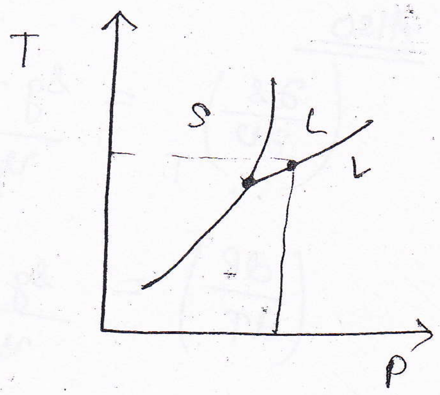
$$\frac{dP}{dT} = \frac{L \cdot H}{T_{sat} \times v_g} = \frac{L \cdot H}{T_{sat} \times \frac{R T_{sat}}{P_{sat}}}$$

$$\boxed{\frac{dP}{dT} = \frac{(L \cdot H) \cdot P_{sat}}{R \cdot T_{sat}^2}}$$

$\Downarrow$

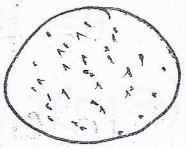
Clausius Clapeyron equation

- It is used for the calculation of enthalpy change associated with phase change from pressure volume and temp.



Mixture of Ideal gases & Real gases

① Ideal gas



$P_1 V = n_1 \bar{R} T$ — ①

$P_2 V = n_2 \bar{R} T$

$P_3 V = n_3 \bar{R} T$

$$\underbrace{(P_1 + P_2 + \cdots)}_{P_t} V = (n_1 + n_2 + \cdots)\bar{R} T$$

$$P_t \times V = (\Sigma n)\bar{R} T \quad \text{— Ⓐ}$$

① ÷ Ⓐ

$$\frac{P_1}{P_t} = \frac{n_1}{\Sigma n} = x_1 \Rightarrow \boxed{\text{mole fraction}}$$

$$\boxed{P_1 = x_1 P_t}$$

② Real gas Requivalent

$P_1 V = m_1 R_1 T$

$P_2 V = m_2 R_2 T$

$$\underbrace{(P_1 + P_2 + \cdots)}_{P_t} V = (m_1 R_1 + m_2 R_2 + \cdots) T \quad \text{— ①}$$

also $P_t \times V = (\Sigma m) \times R_e T$ — ②

① & ②

$$\boxed{R_e = \frac{m_1 R_1 + m_2 R_2 + \cdots}{\Sigma m}}$$

③ C_{p_e} & C_{v_e} .

$$H = H_1 + H_2 + \cdots$$

$$(\Sigma m) C_{p_e} \times T = m_1 C_{p_1} T + m_2 C_{p_2} T + \cdots$$

$$\boxed{C_{p_e} = \frac{m_1 C_{p_1} + m_2 C_{p_2} + \cdots}{\Sigma m}}$$

$$\boxed{C_{v_e} = \frac{m_1 C_{v_1} + m_2 C_{v_2} + \cdots}{\Sigma m}}$$

Equivalent Molecular mass for Air

$$(M_e) \times (\Sigma n) = M_1 \cdot n_1 + M_2 \cdot n_2 + \cdots$$

$$M_e = M_1 \cdot \frac{n_1}{\Sigma n} + M_2 \cdot \frac{n_2}{\Sigma n} + \cdots$$

$$\boxed{M_e = x_1 M_1 + x_2 M_2 + \cdots}$$

Real gases

$$Z = \frac{Pv}{RT}$$

Compressibility factor

For ideal gas,

$$Z = 1$$

$$1 = \frac{Pv_i}{RT} \quad \text{—— ②}$$

$$\frac{Z}{1} = \frac{v_a}{v_i}$$

$$\boxed{Z = \frac{v_a}{v_i}}$$

2

$$\boxed{P_R = \frac{P}{P_{cr}}}$$

$$\boxed{T_R = \frac{T}{C_r}}$$

If $P = 8$, $P_{cr} = 4$
$P = 4$, $P_{cr} = 2$.
Both ~~same~~ behave same

- Compressibility factor(Z) can be viewed as specific volume occupied by the gas to the specific volume predicted by ideal gas eqn.
- Different gases behave differently at same pressure and temp. but they behave approximately at same reduced pressure and temp.
- This behavior is used for drawing compressibility chart which are used in industries for predicting approximate behaviour for the real gases.

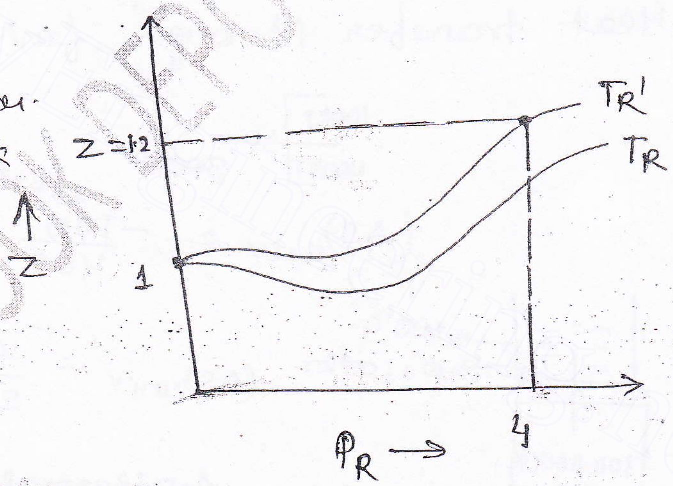
Propane

$P = 8\,bar$, $P_{cr} = 2\,bar$.

$T = 500\,K$, $T_{cr} = 250\,K$

$$Z = \frac{v_a}{v_i} = 1.2$$

$$\boxed{v_a = 1.2\,v_i}$$



Van-der wall equation

$$\left(P + \boxed{\frac{a}{v^2}}\right)\left(v - \boxed{b}\right) = RT$$

b = unit of v.
$\frac{a}{v^2}$ = unit of P.

↓ a/c for vol. occupied by gas molecules.

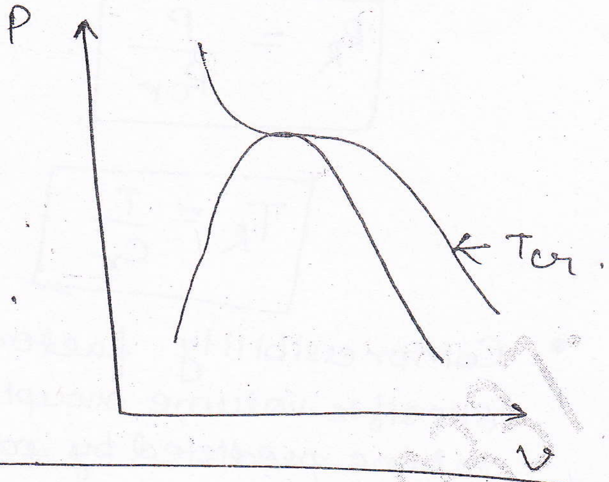
↓ account ~~afess~~ for intermolecular forces.

$$\left(P + \frac{a}{v^2}\right)(v - b) = \bar{R}T$$

↓ $m^3/k\text{-}mol$

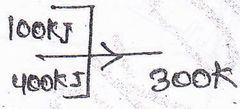
$$\left[\left(\frac{\partial p}{\partial v}\right)_{T=T_{cr}}\right]_{\text{critical pt}} = 0$$

$$\left[\left(\frac{\partial^2 p}{\partial v^2}\right)_{T=T_{cr}}\right]_{\text{at critical pt}} = 0.$$

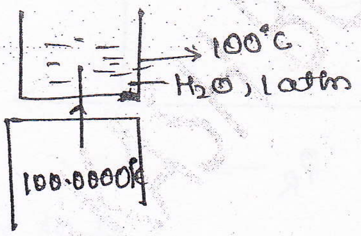


Causes of Irreversibility

- When a high grade energy is converted into low grade energy. **Reason** viscosity, solid friction, electrical friction, Inelastic collision.
- Heat transfer through finite temp. difference.

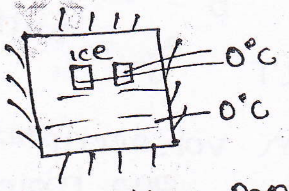


$$(\Delta S)_{univ} = \overset{\rightarrow\text{Entropy less}}{-\frac{100}{400}} + \frac{100}{300} \rightarrow \text{Entropy more}$$



$$(\Delta S)_{univ} = \frac{Q}{273+100.0001} + \frac{Q}{273+100}$$

Isothermal expansion & compression is Internally reversible process,



Reversible Process.

Note :-

- Quasi-static compression or expansion of a gas is a reversible process.

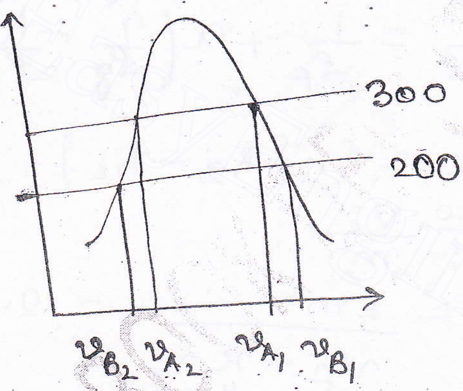
- unrestrain expansion or free expansion.
- Mixing of two dissimilar pure substances.

Note -

- Mixing of two similar substances initially at same state is a reversible process.
- Spontaneous processes are irreversible (occurring in nature)
- Rate of a chemical reaction is directly proportional to rate of entropy generation and degree of completion of a chemical rxn is governed by II^nd law of thermodynamics.

Ch-6

① ⓓ



② ⓐ vol. of vapour = 8 vol. of liquid.

$$m_v v_v = 8 m_l v_l$$

$$\Rightarrow 1 + \frac{v_v}{8 v_l} = \frac{m_l}{m_v} + 1 \Rightarrow \frac{1}{x}.$$

$x = 1$

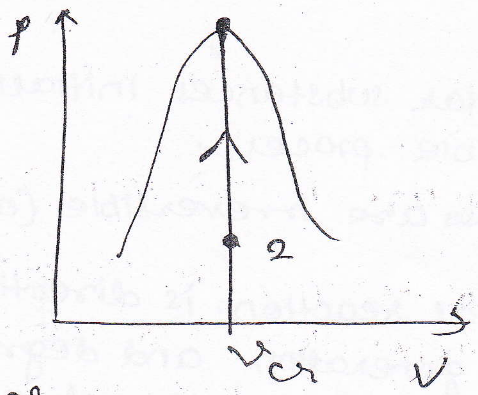
③ ⓒ Refer data from Q⑩

$$u_A = u_B \Rightarrow m_A u_A = m_B \upsilon_B$$

$$\Rightarrow \frac{m_A}{m_B} = \frac{u_B}{u_A} = \frac{u_f + \overset{1}{\cancel{x_B}} u_{fg}}{u_f + \underset{0}{\cancel{x_A}} u_{fg}}$$

④ ⓐ if v is considered as sp. vol

⑤ ⓒ



Rigid vessel
P-v diagram

$v_1 = v_2$

$v_f + x v_{fg} = v_{cr} = 0.00317$

$x = ?$

⑥ ⓒ ⑦ ⓑ $v = v_f + x v_{fg}$

$\frac{1}{\rho} = \frac{1}{\rho_f} + x\left(\frac{1}{\rho_g} - \frac{1}{\rho_f}\right)$

⑧ ⓓ $Q_p = H_2 - H_1 = m\{h_2 - h_1\}$

sp. vol. $v = \frac{V}{m}$

$m = \frac{V}{v} = \frac{1\,m^3}{v_f + \underset{0.4}{\underset{\Downarrow}{x}}\, v_{fg}} = 2.8175$

⑱ $h_1 = h_f + \underset{0.4}{\underset{\Downarrow}{x}}\, h_{fg} = 1385.5\ kJ/kg$

h_2 (saturate liquid) $= 125.77$

then find Q_p.

⑨ ⓑ $s_g - s_f = \frac{h_{fg}}{273 + 99.63}$

(10) ⓒ Const. vol → Heat supplied ΔU

$Q_v = U_2 - U_1$

$= m\{u_2 - u_1\}$

$m = \frac{V}{v} = \frac{20}{2583.6} = 102.18\ kg.$

$\left(\frac{\partial v}{\partial T}\right)_{3^\circ} < 0$, $\left(\frac{\partial v}{\partial T}\right)_{5^\circ} > 0$

$\left(\frac{\partial v}{\partial T}\right)_{p} = -\left(\frac{\partial s}{\partial P}\right)_{T}$ $\boxed{\begin{matrix} \overleftrightarrow{T \quad P} \\ V \quad S \end{matrix}}$

⑦ c.c eqn ⓑ. compare with c.c eqn & differentiate.

⑧ ⓐ ⑨ ⓑ ⑩ ⓒ ⑪ ⓑ ⑫ ⓒ ⑬ ⓓ

⑭ ⓑ ⑮ ⓑ ⑯ ⓐ ⑰ ⓑ ⑱ ⓓ ⑲ ⓐ

Riged vessel , $v_1 = v_2$

$$2583.6 = v_{f_2} + x_2 v_{fg} \Rightarrow x_2 = 0.114$$

$u_2 = u_{f_2} + x_2 u_{fg_2} \rightarrow 0.1\ MPa$

$u_1 = u_{f_1} + \overset{1}{\cancel{x_1}} u_{fg_1} \rightarrow 1\ MPa$

$= u_{g_1} =$ ⓒ

(11) ⓐ

(12) (c) $Q_p = \Delta H$ (Heat supplied at const press.)

$Q_p = m\{h_2 - h_1\}$.

$10 = 2\{h_2 - h_1\}$.

$5 = \{(h_f + x h_{fg}) - h_f\} = x h_{fg}$

$\Rightarrow x = \dfrac{5}{2015.3} \Rightarrow Ans = 2x \times 10^3$

⑬ ⓑ ⑭ ⓑ ⑮ ⓒ ⑯ ⓑ ⑰ ⓓ ⑱ ⓐ

⑲ ⓒ (20) ⓒ (21)(d) (22) (c) $\partial^3 P / \partial v^3 < 0$.

(23) ⓑ min → $s_1 = s_2$.

(24) (a) (25) (d) (26) b [initial u_f, s_f, h_f, s_g, u_g & h_g)

$u_f < h_f$

$u_g < h_g$

(ch-7)

① ⓓ clausius - clapeyron ② ⓓ ⓐ

③ ⓑ c.c eq^n $\dfrac{dP}{dT} = \dfrac{L \cdot H \cdot P}{RT^2}$.

$$\int \frac{dP}{P} = \frac{L \cdot H}{R} \int_1^2 \frac{dT}{T^2}$$

(4) $G - F = (H - Ts) - (U - Ts)$

$= H - U = pv = mRT$.

(5) (c) (6) (d)